REGIONAL GEOCHEMICAL RECONNAISSANCE

AN INTRODUCTION TO THE INTERPRETATION OF DATA FROM CENTRAL BAFFIN ISLAND, DISTRICT OF FRANKLIN

E.M. CAMERON

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GENERAL INTRODUCTION

Geochemical data are an essential component of the comprehensive geological description of any area or country. This paper is one of a series of overviews on the geochemistry of regions of Canada.

The Geological Survey of Canada commenced regional surveys involving systematic geophysical measurements in 1949, with an aeromagnetic survey covering 30 000 km^2. By 1961 such regional geophysical surveys had expanded towards national coverage through a jointly funded Federal-Provincial program.

GSC first experimented with regional geochemical surveys in the late 1950s and continued up to the early 1970s. As a result of this work, the value of such surveys was established, methods were perfected, and the importance of sample collection and analytical controls was recognized[1]. The commencement of a large scale national program of regional geochemical surveys then waited upon the availability of funding. This opportunity arose with the energy crisis of 1973, which led to the Federal-Provincial Uranium Reconnaissance Program. This program was initiated with the support of the 1974 Annual Conference of the Provincial Ministers of Mines, and it commenced in 1975 with as expected life of 10 years. Costs for work within the provinces were shared between the Federal and Provincial governments, whilst the Federal government was wholly responsible for the cost of work in the Territories.

Between 1975 and 1979, when the Uranium Reconnaissance Program was terminated by the Federal government for economic reasons, work took place in seven provinces and all the Territories. During this period approximately 900 000 km^2 in different parts of Canada were covered by geochemical surveys. The areas covered were selected according to a variety of criteria. Work in each of the provinces was conducted through a joint Federal-Provincial management committee. Since the funds available (approximately $1.25 million per year for geochemistry) were not large in relation to the magnitude of the task, blanket coverage was not possible. Areas for geochemical surveys were selected partly on the basis of suspected exploration potential, as indicated by existing mineral occurrence and geological information, and partly to demonstrate the applicability of geochemistry in a variety of terrains.

Following on the termination of the Uranium Reconnaissance Program in 1979 most of the participating provinces indicated their interest in continuing the surveys in their areas of jurisdiction under other financial arrangements. These have varied from year to year and from province to province. They range from mostly provincial funding in British Columbia and Ontario, to wholly federal funding as in Newfoundland. Since 1979 the Geological Survey of Canada has conducted one federally funded survey

[1] These general considerations have been described by Cameron and Hornbrook (in Exploration for Uranium Ore Deposits, International Atomic Energy Agency, Vienna, 1976, p. 241-264) and Coker, Hornbrook and Cameron (in Geophysics and Geochemistry in the Search for Metallic Ores; Geological Survey of Canada, Economic Geology Report 31, 1979, p. 435-478).

INTRODUCTION GÉNÉRALE

Les données géochimiques sont essentielles à la description détaillée de la géologie de n'importe quel pays ou région. Le présent document fait partie d'une série d'aperçus sur la géochimie régionale du Canada.

La Commission géologique du Canada a commencé en 1949 à effectuer des levés régionaux, dont la cueillette systématique de données géophysiques, par un levé aéromagnétique couvrant 30 000 km^2. En 1961, ces levés géophysiques régionaux ont été étendus à tout le Canada en vertu d'un programme fédéral-provincial à frais partagés.

La CGC a exécuté ses premiers levés géochimiques régionaux à la fin des années 50 et poursuivi ses activités dans ce domaine jusqu'au début des années 70. Ces travaux ont permis d'établir la valeur de ce type de levés, de mettre au point le méthodes et de montrer l'importance de l'échantillonnage et de la vérification des résultats d'analyses[1]. La mise en oeuvre d'un vaste programme national de levés géochimiques régionaux a dû attendre que les fonds requis deviennent disponibles. L'occasion attendue s'est manifestée au moment de la crise de l'énergie en 1973, phénomène responsable de la mise sur pied du Programme fédéral-provincial de recherche pour l'uranium. Ce programme a été lancé avec l'appui de la conférence de 1974 des Ministres provinciaux des mines, et mis en oeuvre en 1975 avec une durée prévue de dix ans. Les frais engagés dans les provinces ont été partagés entre les gouvernements fédéral et provinciaux, bien que le gouvernement fédéral ait assumé entièrement le coût des travaux exécutés dans les territoires.

Entre 1975 et 1979, lorsque le gouvernement fédéral a mis fin au Programme de recherche pour l'uranium pour des raisons économiques, des travaux avaient été exécutés dans sept provinces et les deux territoires. Au cours de cette période, une superficie d'environ 900 000 km^2 répartie dans différentes régions du Canada a fait l'objet de levés géochimiques. Les régions couvertes ont été choisies en fonction de divers critères. Dans chaque province, les travaux ont été exécutés par l'entremise d'un comité de gestion fédéral-provincial. Etant donné que les fonds disponibles (environ 1,25 million de dollars par année pour la géochimie) n'étaient par considérables par rapport à l'ampleur de la tâche, une couverture complète n'a pas été possible. En ce qui concerne les levés géochimiques, les régions ont été choisies, d'une part, parce qu'elles étaient susceptibles de renfermer des gisements de minéraux, tel qu'indiqué par les venues minérales connues et les données géologiques disponibles et, d'autre part, afin de démontrer l'applicabilité de la géochimie à différents types de terrains.

En 1979, une fois terminé le Programme de recherche pour l'urnaium, la plupart des provinces qui y avaient participé se sont dites intéressées à poursuivre les levés dans les régions placées sous leur compétence, en utilisant d'autres arrangements financiers. Ces derniers ont varié d'année en année et d'une province à l'autre. Ils vont du financement provenant surtout du gouvernement provincial, comme c'est le cas en Colombie-Britannique et en Ontario, jusqu'au financement issu entièrement du gouvernement fédéral, tel

[1] Ces considérations d'ordre général ont été décrites par Cameron et Hornbrook (dans Exploration for Uranium Ore Deposits, Agence Internationale de l'Energie Atomique, Vienne, 1976, p. 241-264) et par Coker, Hornbrook et Cameron (dans Geophysics and Geochemistry in the Search for Metallic Ores; Geological Survey of Canada, Economic Geology Report 31, 1979, p. 435-478).

in the Territories (Nahanni, Yukon). As far as possible, the areas surveyed have coincided with NTS sheets boundaries in order to facilitate eventual national compilations. Most of the regional geochemical survey work has been undertaken by contractors. Sample collection, sample preparation, and different types of analytical services have been performed by separate organizations. Twelve companies have taken part in these operations. The Geological Survey of Canada has been responsible throughout for overall co-ordination, compilation and checking of data. Commencing in 1976, all data (66 different sets) have been released on GSC Open File under the title of National Geochemical Reconnaissance, and this term has been commonly used in related published literature.

This paper is one of a series which has three main aims: to serve as a reminder of the extent to which geochemical reconnaissance data are available for various parts of the country; to make general comments upon the relationship between the observed surficial geochemistry and the general and economic geology of various regions; and to provide specific examples showing how these geochemical data may be interpreted. Although the prime purpose of the geochemical surveys is as a guide to mineral exploration, the same data are of value to environmentalists, and in populated areas to agriculturalists and health authorities.

Regional geochemistry is based either on the sampling of lakes, wherever they are sufficiently abundant to permit one sample to be taken every 13 km^2, or in mountainous areas on the sampling of streams, at a similar site density. In special circumstances, where additional funding has been available, more detailed sample densities have been employed. At each site both sediment and water is collected. Sediment samples have been routinely analyzed for U, Zn, Cu, Pb, Ni, Co, Mo, Ag, Mn and Fe, and loss on ignition. In some areas Ba, W, Sn, As, Sb, V and Hg have also been determined. All waters have been analyzed for U, and commonly for F. From 1976 onwards pH measurements have been made on all water samples.

For the regional surveys, sample collection and sample preparation procedures, analytical methods and repeatability of results have all been tightly specified and controlled. This has been done in order to obtain consistent data between different areas, between work undertaken in successive years, and between results from different analytical laboratories. In this way the data base contributes to the eventual completion of a national geochemical reconnaissance, providing maps which have sufficient reliability to be used as an essential component of resource assessment, mineral exploration and geological mapping.

qu'à Terre-Neuve. Depuis 1979, la Commission géologique du Canada a exécuté dans les territoires (Nahanni, au Yukon) un levé financé par le gouvernement fédéral. Dans la mesure du possible, on a fait coincider les régions à l'étude avec les feuilles de cartes du SNRC en vue de faciliter une éventuelle compilation des données pour tout le Canada. La plupart des levés géochimiques régionaux ont été exécutés par des entrepreneurs privés. Plusieurs organismes se sont chargés du prélèvement et de la préparation des échantillons, ainsi que des différents services d'analyse. Douze sociétés ont pris part à ces activités. La Commission géologique du Canada a assumé l'entière responsabilité de la coordination, de la compilation et de la vérification de tous les résultats. A partir de 1976, toutes les données (66 séries différentes) ont été publiées dans le dossier public de la CGC intitulé «National Geochemical Reconnaissance», et cette appellation a été couramment utilisée dans les publications concernant le sujet.

Le présent document fait partie d'une série qui a trois objectifs principaux: de rappeler à quel point sont disponibles, pour diverses parties du pays, les données géochimiques de reconnaissance; de présenter des commentaires d'ordre général en ce qui concerne la relation entre la géochimie de surface et la géologie générale et la géologie économique, dans diverses régions; et de fournir des exemples précis montrant comment les données géochimiques peuvent être interprétées. Bien que le but premier des levés géochimiques soit la recherche de minéraux, ils peuvent aussi servir aux environnementalistes et, dans les régions habitées, aux agronomes et aux services d'hygiène.

Les levés géochimiques régionaux sont fondés sur l'échantillonnage des lacs, là où ceux-ci sont assez nombreux pour permettre la cueillette d'un échantillon à tous les 12 km^2 ou, dans les régions montagneuses, sur l'échantillonnage des cours d'eau, à intervalles semblables. Lorsque des fonds additionnels étaient disponibles par suite de circonstances spéciales, on a utilisé un réseau d'échantillonnage aux mailles plus étroites. A chaque station d'échantillonnage, on a receuilli des sédiments et de l'eau. Les échantillons de sédiments ont été systématiquement analysés afin d'en évaluer la teneur en U, Zn, Cu, Pb, Ni, Co, Mo, Ag, Mn et Fe, et on a déterminé la perte au feu. Pour certaines régions, on a également dosé le Ba, le W, le Sn, l'As, le Sb, le V et le Hg. Tous les échantillons d'eau ont été analysés afin de déterminer la présence de l'uranium, et souvent, du fluor. A partir de 1976, on a déterminé le pH de chaque échantillon d'eau.

En ce qui concerne les levés régionaux, les méthodes de prélèvement et de préparation des échantillons, les méthodes d'analyse et la répétabilité des résultats, ont toutes été étroitement vérifiées et décrites en détail. Cette initiative avait pour but de s'assurer de l'uniformité des données provenant de différentes régions, de travaux s'échelonnant sur plusieurs années successives et de résultats d'analyses émanant de différents laboratoires. De cette façon les résultats pourront éventuellement s'incorporer à l'ensemble des données géochimiques de reconnaissance du Canada en fournissant des cartes ayant un degré de fiabilité suffisant pour être utilisées à titre d'éléments essentiels dans l'évaluation des ressources, la recherche de minéraux et la cartographie géologique.

It is not the intention of this series of overview papers to seek to identify every anomalous feature and determine its cause. This is only possible where there have been comprehensive follow-up investigations. Each of these must involve detailed field and laboratory work tailored to the problems presented by each anomaly. Only a very small percentage of the many anomalies which are present in the data have been investigated systematically by the Geological Survey of Canada or provincial agencies because of the limited human and material resources available to conduct such work. The major effort of examining anomalies has been undertaken by industry, but only in a small percentage of cases, where there have been discoveries of commercial interest, do such results become known and documented.

It should be noted that it has not been possible for GSC to undertake follow-up investigations in this central Baffin Island survey area. Thus this paper is an example of the type of preliminary data assessment required prior to field follow-up. The author makes two important points: that interpretations without the benefit of field work are speculative and that interpretation of geochemical data is best done with knowledge of all the other geoscientific information pertinent to the area.

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Le but de cette série d'aperçus n'est pas d'identifier toutes les anomalies ni d'en déterminer la cause. Cela ne peut se faire qu'aux endroits où l'on a procédé à des études complémentaires approfondies. Chacune de ces études doit comprendre un examen détaillé sur le terrain et en laboratoire adopté à chaque anomalie. Seul un très faible pourcentage des nombreuses anomalies qui existent dans les données a été systématiquement examiné par la Commission géologique du Canada ou par des organismes provinciaux parce que les ressources humaines et matérielles disponibles pour ce genre d'activité sont restreintes. Le secteur industriel a fourni le principal effort dans la tâche d'examiner les anomalies, mais c'est seulement dans un nombre limité de cas, c'est-à-dire, à l'occasion de découvertes présentant un intérêt commercial, que ces travaux ont été publiés et documentés.

Il est à noter que la CGC se voit dans l'impossibilité d'entreprendre ces recherches dans cette région du centre de l'île Baffin. Par contre, cette étude montre bien la nécessité d'avoir des donneés préliminaires pertinentes avant d'entreprendre ces recherches. L'auteur met en évidence deux points importants: toute interprétation est hasardeuse si elle n'est pas appuyée par des travaux de terrain et aussi toute interprétation à partir de données géochimiques sont conséquentes que si elle est mise en relation avec toutes les autres données provenant d'etudes géoscientifiques diverses de la région étudiée.

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REGIONAL GEOCHEMICAL RECONNAISSANCE: AN INTRODUCTION TO THE INTERPRETATION OF DATA FROM CENTRAL BAFFIN ISLAND, DISTRICT OF FRANKLIN

Abstract

Results from lake sediment and water geochemical survey of 26 000 km^2 of Baffin Island are shown on 1:2 000 000 colour maps, accompanied by discussions on lithology, mineral deposits, and surface environment. The maps are supplemented by maps of bedrock geology, metamorphic geology, glacial geology, gravity, and aeromagnetics.

The area, part of Foxe Fold Belt, comprises Aphebian supracrustal rocks, bounded to the north and south by Archean terranes.

Within the Foxe Fold Belt there are strong base metal and arsenic anomalies in lake sediments. The base metal anomalies are the product of high element contents in some lower Piling metasediments (quartzite, marble, dolomite, sulphidic schist, iron-formation, mafic volcanics) and favourable present-day conditions for anomaly formation. The schist and iron-formation have high metal contents, presumably from volcanic-exhalative activity. Recent oxidation of sulphidic schists produces acidic water that dissolves base metals, which are then precipitated in lake sediments. Where water passes from acidic schist to alkaline marble and dolomite, there is strong precipation of base metals. The mineral potential of these metalliferous metasediments is unknown. They are correlated with rocks hosting the Sorte Engel lead-zinc deposit on West Greenland.

Upper Piling turbidites that form the axial portion of the fold belt host intense lake sediment anomalies for arsenic. Because of the gold-arsenic-turbidite-association, further investigation is warranted.

Archean granite-gneiss terrane north of the fold belt has been subdivided into blocks based on geochemical variation in lake sediments. Base metal anomalies probably relate to metamorphosed volcanics. Hudsonian granitoids and Archean gneiss along the northern boundary of the fold belt form a strongly anomalous zone for uranium.

Résumé

Les résultats d'un levé géochimique portant sur 26 000 km^2 d'eaux et de sédiments lacustres de l'île Baffin sont illustrés sur des cartes en couleur de 1/2 000 000 et s'accompagnent de commentaires sur la lithologie, les gîtes minéraux et l'environnement de surface. Ces cartes sont complétées par des cartes sur la géologie de la roche en place, la géologie des roches métamorphiques, la géologie glaciaire et la gravité et des cartes sur le magnétisme établies à partir de données aériennes.

Cette région qui fait partie de la zone de plissement de Foxe comprend des roches supra-crustales de l'Aphébien, limitées au nord et au sud par des terrains de l'Archéen.

À l'intérieur de la zone plissement de Foxe, on trouve dans les sédiments lacustres des anomalies élevées de métaux communs et d'arsénic. Les anomalies élevées de métaux communs résultent de leur forte présence dans les sédiments métamorphisés du Piling inférieur (quartzite, marbre, dolomite, schiste sulfurifère, formation de fer, roches volcaniques mafiques) et des conditions actuellement propices à la production d'anomalies. Le fait que la formation schiste et fer ait une teneur élevée en métaux est probablement attribuable à une activité volcanique d'exhalaison. L'oxydation récente des schistes sulfurifères a eu pour effet d'acidifier l'eau, d'où une dissolution des métaux communs qui a entraîné leur précipitation dans les sédiments lacustres. Aux endroits où elle passe du schiste acide au marbre et au dolomite alcalins, l'eau provoque une forte précipitation de métaux communs. Le potentiel minéral de ces sédiments métamorphisés métallifères est inconnu. Il existe une corrélation entre elles et les roches encaissantes du gisement plombozincifère Sorte Engel du Groenland occidental.

Les turbidites du Piling supérieur qui forment la partie axiale de la zone de plissement présentent des sédiments lacustres à fortes anomalies d'arsénic. En raison de l'association or-arsénic-turbidite, il est valable de poursuivre les recherches.

La zone granite-gneiss de l'Archéen, au nord de la zone de plissement, a été subdivisée en blocs selon la composition géochimique des sédiments lacustres. Les anomalies de métaux communs sont probablement liées à la présence de roches volcaniques métamorphisées. Les granitoides de l'Hudsonien et les gneiss de l'Archéen qui longent la limite septentrionale de la zone de plissement constituent une zone d'anomalie marquée d'uranium.

INTRODUCTION

This report serves as an introduction to regional geochemical reconnaissance data for a portion of Baffin Island (Fig. 1) and provides the generalized type of interpretation of these data that normally precedes field follow-up.

The survey of this 26 000 km^2 area in 1978 evolved from studies commenced almost a decade earlier by the Geological Survey of Canada. These were aimed at developing a geochemical method for the rapid evaluation of the mineral potential of large areas of the Canadian Shield. The method adopted was the collection and analysis of centre-lake sediments and lake waters at a site density of one per 13 km^2.

The choice of lakes was dictated by their abundance in glaciated, shield terrain. The lakes can readily be sampled from a float-equipped helicopter. Elements enter the lakes in solution and as suspended sediment; lake materials serve as a composite sample of the drainage basin. The success of the method in outlining mineralization depends largely on the oxidation and dissolution of minerals containing metals of economic value, such as sulphides and uraninite, followed by the transportion of these elements to the lakes in solution and precipitation in sediment. Centre-lake sediment is sampled in preference to nearshore sediment, because it is more uniform and because it maximizes the contribution of elements carried into the lake in solution. The sulphide minerals that are oxidized may be in place in bedrock, or, alternatively, in till that has been displaced by ice movement from the bedrock source.

In interpreting regional geochemical reconnaissance data, care should be taken to consider a number of factors that influence the dispersion of elements and their precipitation in lake sediments. The pH of surface waters determines how readily an element may be carried in solution and then precipitated. Uranium and Mo, for example, are most soluble in alkaline waters, while most base metals dissolve best in acidic waters. Some metals found in sulphide deposits do not form readily soluble compounds. One example is Pb. In a deposit containing both Zn and Pb, the latter will be retained in the soils near the deposit, while the Zn will travel to the lakes. Studies around mineralization in the northern Shield have shown that Pb, Ag, Au and Hg are least mobile; As and Cu are of intermediate mobility; and U, Zn, Ni and Co are most widely dispersed (Cameron, 1977a, 1980).

The methods used to prepare and analyze the samples are summarized in Appendices A and B. Note that the detection limit of the method for a given element may be greater than the concentration present in some samples. Silver is an example of an element that has been detected in only a few sample of lake sediment from this survey area. The regional geochemical reconnaissance analytical program uses quality control methods to ensure consistent results within the survey area and between areas in different parts of Canada. More detailed information on this method of geochemical reconnaissance will be found in papers listed in the Selected Bibliography.

The survey area mainly comprises gently rolling terrain with elevations of about 150 m in the west and up to 1000 m in the east. The western boundary is a scarp which forms the coast of Baffin Island or marks the limit of lower Paleozoic sedimentary rocks forming the Foxe Basin Lowlands. The eastern boundary of the area is formed by the Barnes Ice Cap and by the flanks of the highlands that form the eastern coast of Baffin Island. The survey area was sampled during the period August 12 to September 4, 1978.

Acknowledgments

The regional geochemical reconnaissance survey of Baffin Island was carried out by contract to the Geological Survey of Canada, with Marshall Macklin Monoghan Ltd. responsible for sampling; Golder Associates for sample preparation; Chemex Labs Ltd., Barringer Magenta Ltd. and Atomic Energy of Canada Ltd. for chemical analyses. N.G. Lund of the GSC performed data management and E.H.W. Hornbrook and J.J. Lynch, both of the GSC, supervised the contracts and directed the work.

I am indebted to W.C. Morgan for clarifying points relating to the geology of Baffin Island and for placing his rock collection at my disposal. The geochemical colour maps were produced by D.J. Ellwood and the aeromagnetic colour map by S.D. Dods. I thank G.E.M. Hall who is co-ordinating the series of overviews on regional geochemistry.

GEOLOGICAL SUMMARY

This summary is based on the papers listed in section A of the Selected Bibliography. The principal geological feature of the survey area is the Foxe Fold Belt (Fig. 1). It is composed of Aphebian (2.5 to 1.8 Ga) supracrustal rocks, the Piling Group, that were folded, metamorphosed and intruded by Hudsonian (about 1.8 Ga) granitoids (Fig. 2). In Canada, this belt is 800 km long, stretching from Melville Peninsula in the west to the east coast of Baffin Island; it may also extend to Greenland.

The Aphebian rocks lie on an Archean granite-gneiss terrane, which has a complex geological history. The earliest Archean rocks are mainly granitic and formed a surface on which the Mary River Group, also of Archean age, was deposited. This group comprises eugeoclinal sediments, including iron-formation, mafic to felsic volcanics, ultramafic rocks, and anorthosite. Archean history closed with the Kenoran Orogeny at about 2.6 Ga, causing intense folding, regional metamorphism and granitic intrusion. The great majority of the Archean exposed in the area (Fig. 2) is gneiss, migmatite and granitoids, the latter ranging in composition from quartz monzonite to granodiorite. There are small outcrops of recognizable Mary River metasedimentary and metavolcanic rocks in the very north of the survey area (Morgan, 1983).

The lower Piling Group shows marked facies variation across the fold belt (Fig. 3). The basal quartzite is approximately 1000 m thick in the southern part of the belt, but is thin along the northern margin. In the north this is succeeded by 200 m of marble and dolomite, which is largely absent in the south. A thick (about 800 m) amphibolite-ultramafic unit of restricted areal distribution is present in the south (Fig. 3) and is interpreted to be the metamorphosed equivalent of mafic lavas and ultramafic sills. Associated with this is a graphitic, sulphide schist and paragneiss unit, up to 300 m thick, which is widely distributed in the fold belt. It overlies the quartzite, or the marble and dolomite, where the latter is developed. Beds of sulphide and rare oxide facies iron-formation, up to 35 m thick, occur in the graphitic schist and amphibolite. The upper Piling Group comprises a 3000 m section of metamorphosed greywacke and shale, interpreted to be turbidite (Henderson and Tippett, 1980).

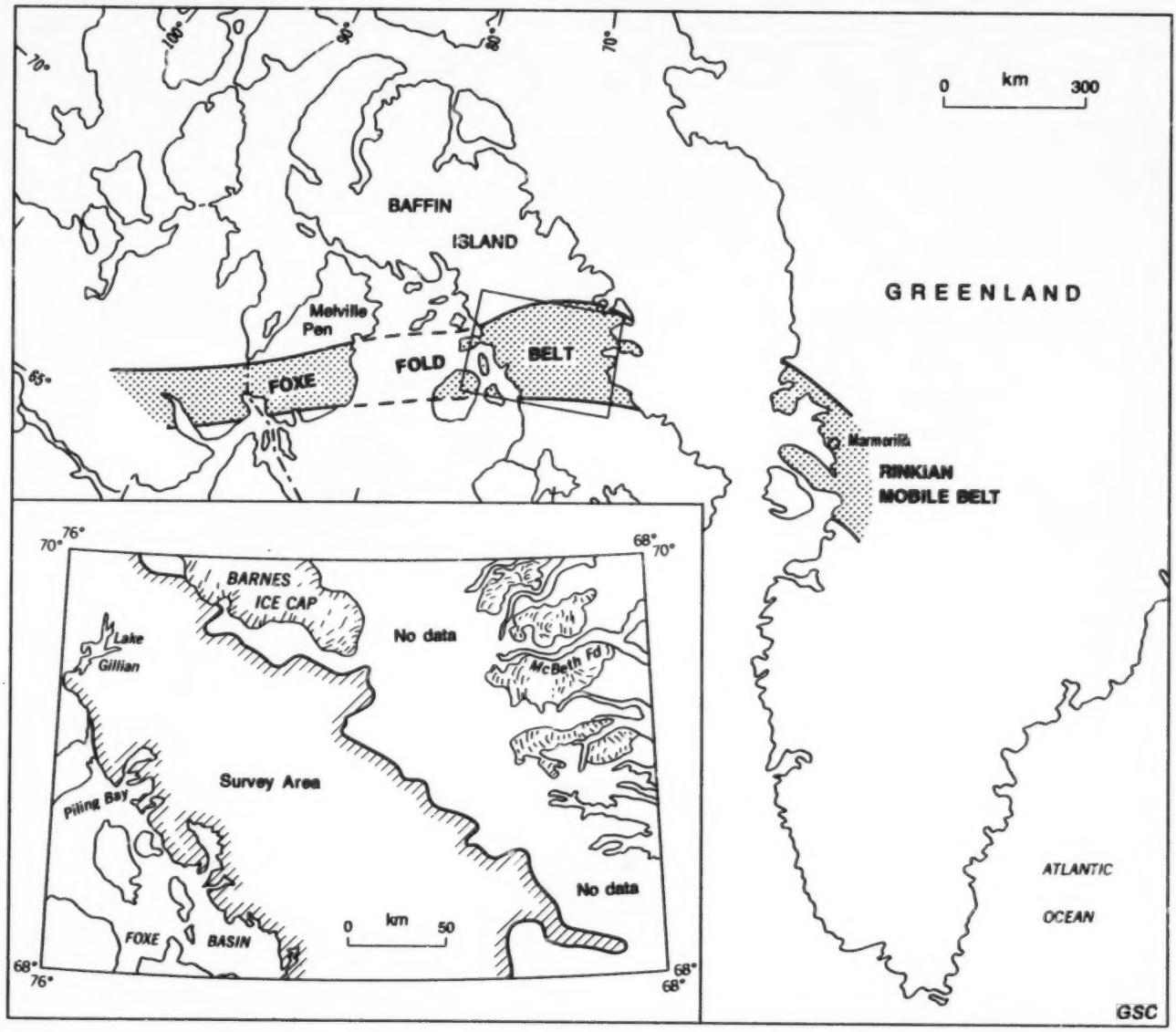

Figure 1. *Foxe Fold Belt and Rinkian mobile belt prior to drift of Canada from Greenland, showing the location of the survey area in central Baffin Island.*

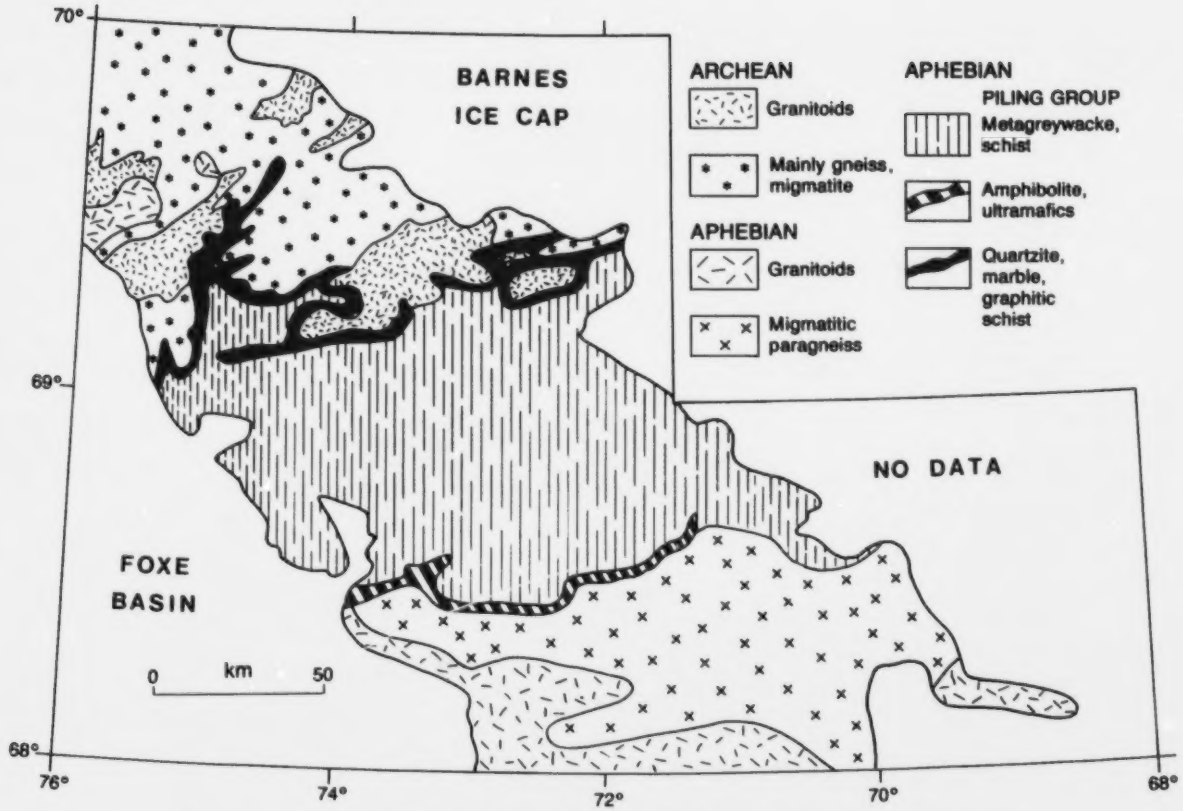

Figure 2. *Geological map of the Baffin Island regional geochemical reconnaissance area. A transparent overlay of Figure 2 is in the pocket, at rear.*

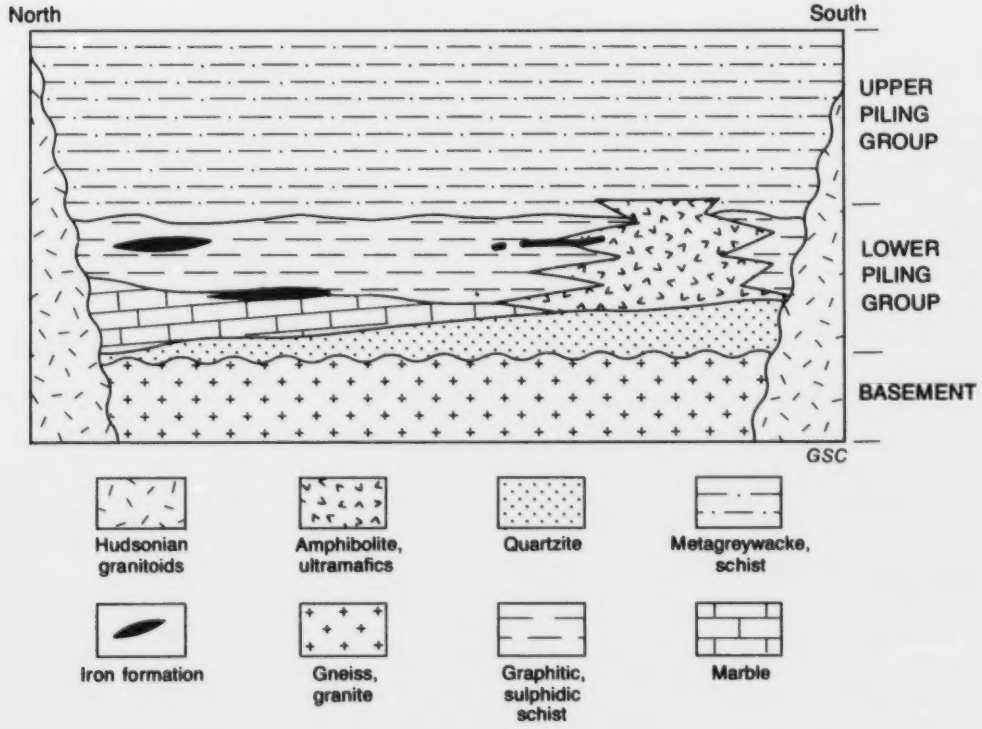

Figure 3. *Stratigraphic cross-section across the Foxe Fold Belt.*

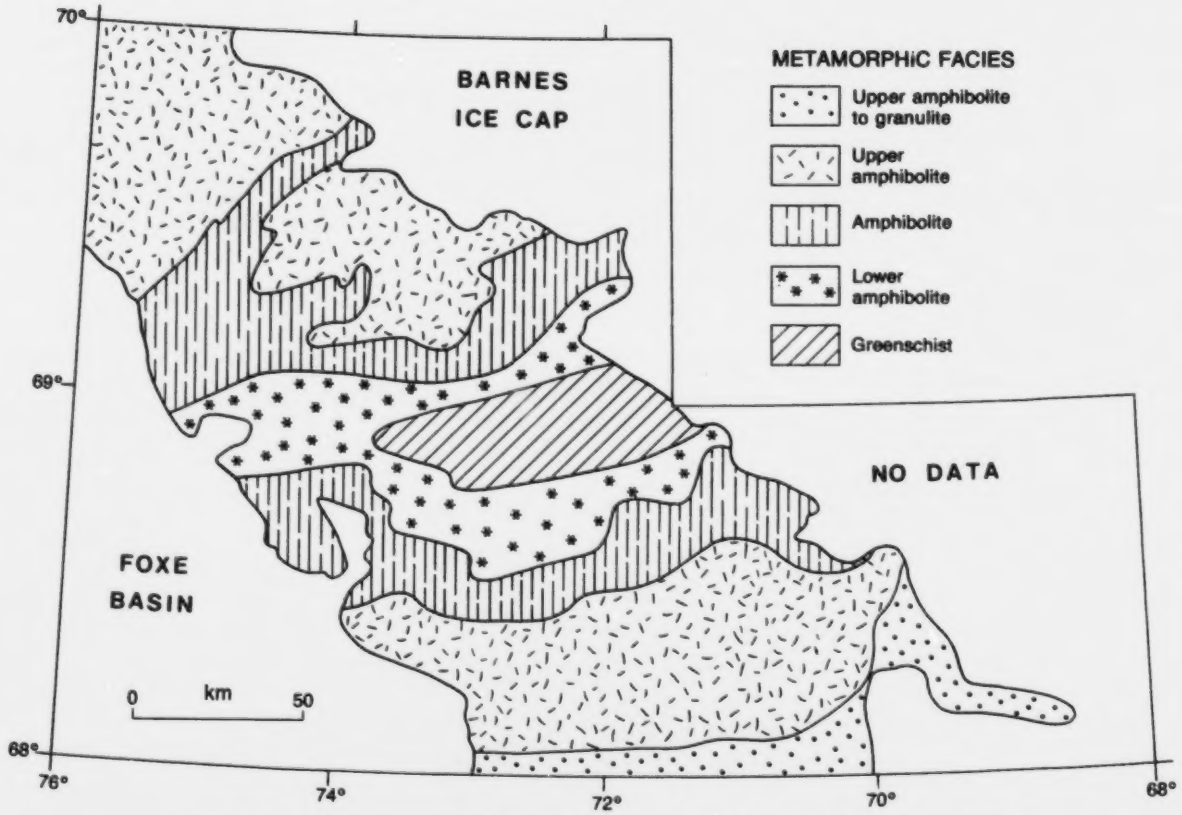

Figure 4. Metamorphic map (adapted from Geological Survey of Canada Map 1475A).

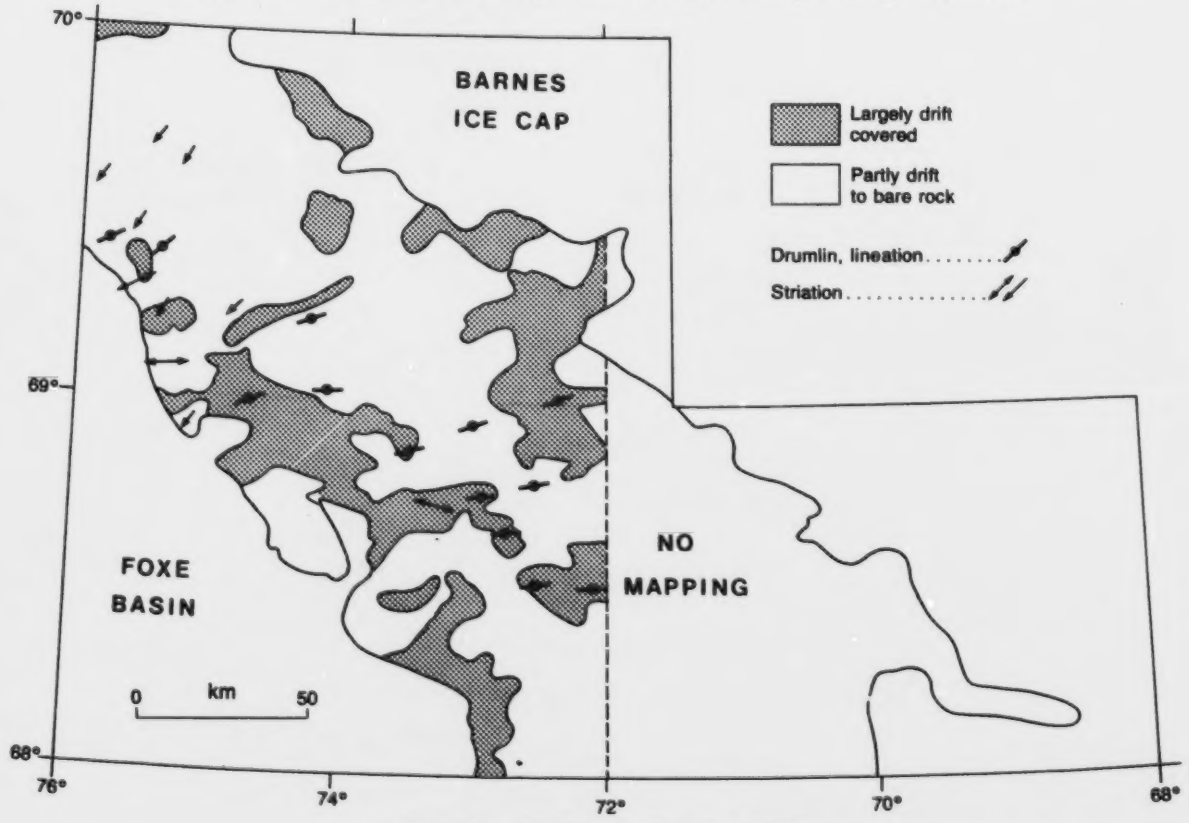

Figure 5. Glacial map (from Sim, 1964).

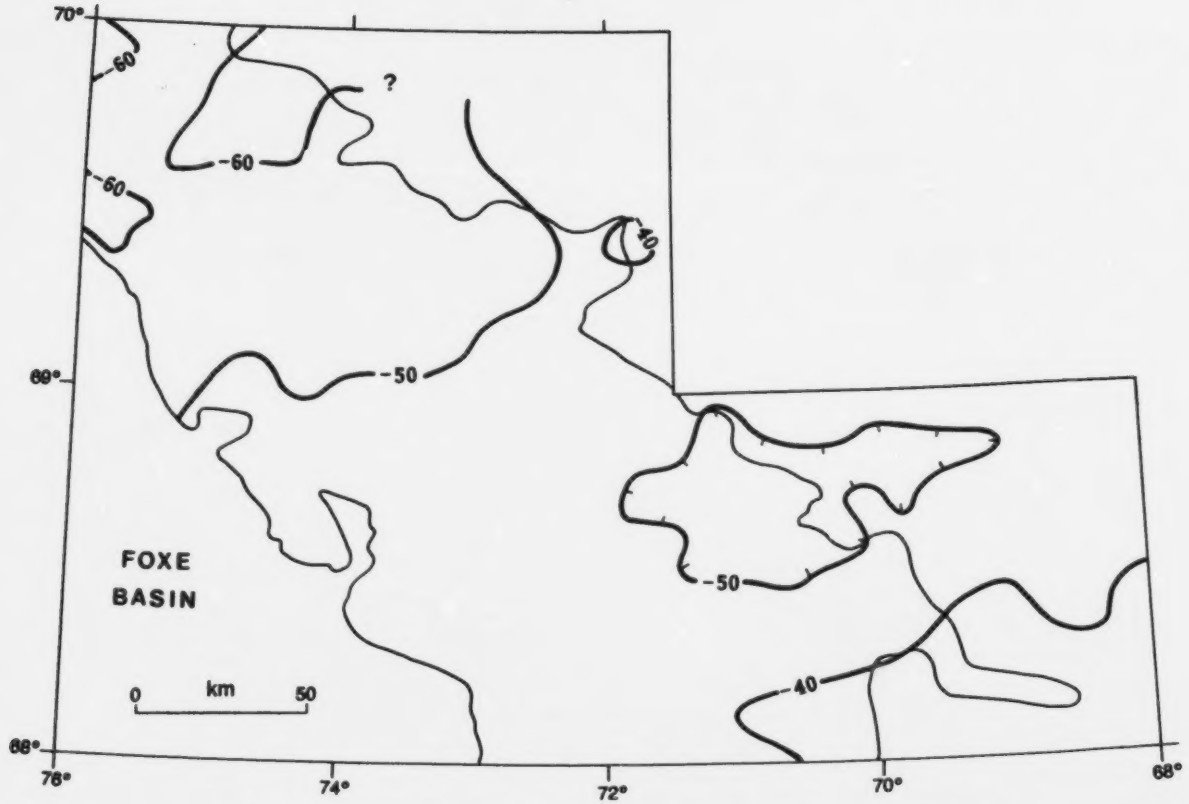

Figure 6. Bouguer gravity anomaly map (from Earth Physics Branch, Map 80-1).

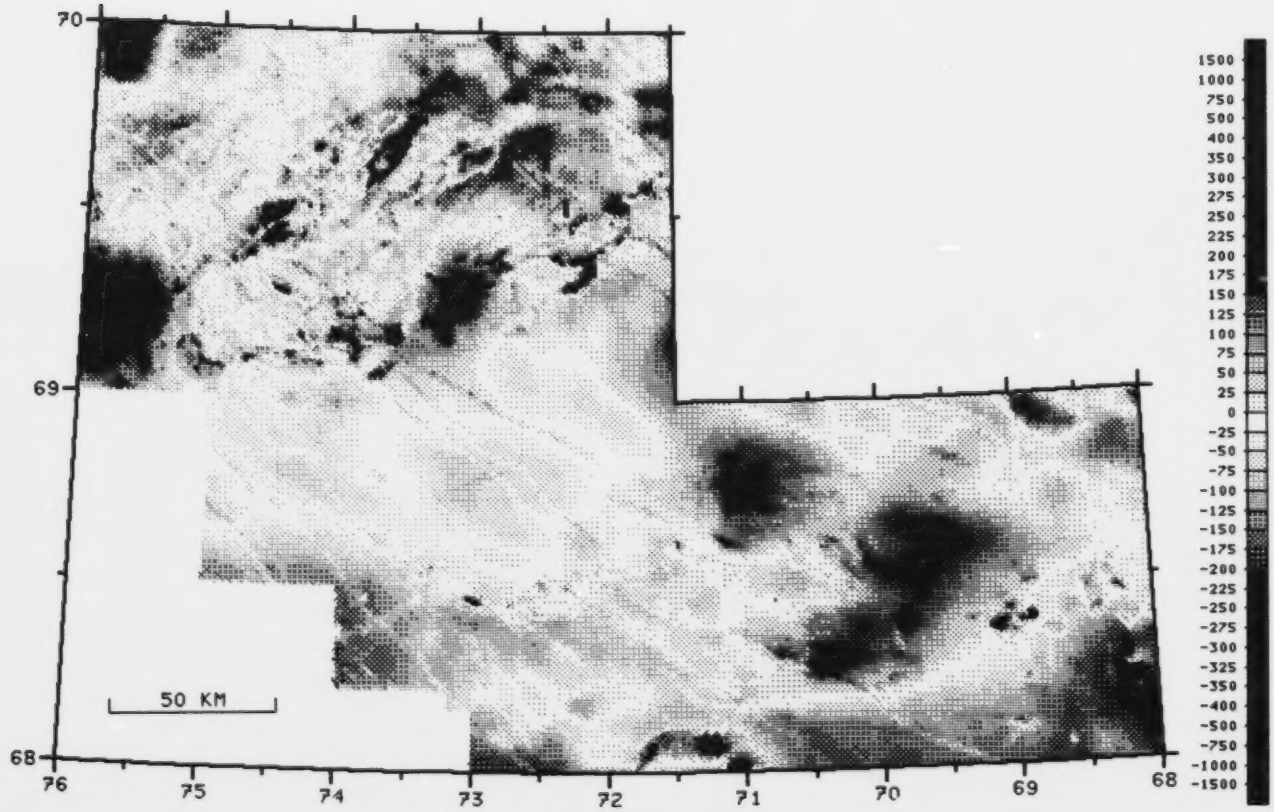

Figure 7. Magnetic anomaly map.

The fold belt has been subject to several episodes of folding. This has produced a synclinorium, with the upper Piling forming the centre of the belt and the lower Piling, strongly infolded with basement rocks, the northern margin. Note that basement-cored domes, mantled by lower Piling, occur immediately south of the amphibolite-ultramafic unit, but are too small to be shown on Figure 2. The lowest metamorphic grade, which is lower greenschist, occurs in the axial, turbidite-cored portion of the fold belt and the grade increases to upper amphibolite or granulite facies near the northern and southern boundaries of the survey area (Fig. 4). As the metamorphic grade increases, so does the abundance of migmatite, pegmatite and granitic plutons of Hudsonian age. Pegmatites are particularly abundant in pelites near the basement contact.

Little work has been done on the glacial history of the region, except for that summarized in Figure 5 by Sim (1964). Various glacial features have an east-west to northeast-southwest orientation, but only a few of these provide a specific direction for glacial flow and these indicate movement southwestward from the Barnes Ice Cap. Other evidence suggests that ice centred in Foxe Basin moved eastward and northeastward. This includes roches moutonnées and erratics of limestone and dolomite across Baffin Island, presumably derived from the lower Paleozoic strata of the Foxe Basin Lowlands.

Gravity and magnetic anomaly maps of the survey area are shown in Figures 6 and 7.

INTERPRETATION

The GSC has carried out follow-up studies of several regional geochemical reconnaissance surveys. Such field work provides the only sound basis for identifying the sources of geochemical anomalies. No follow-up work has yet been carried out in this area, mainly because of its remoteness and high cost of field operations. The interpretations that follow should, therefore, be considered as an example of the preliminary investigations that normally precede follow-up field work and which are designed to outline targets for more detailed study. For some of the geochemical features shown on the colour maps, no reasonable explanation can be provided without field studies.

Since lake sediment and water surveys are regional in scope they should be examined in relationship to maps at the same scale of bedrock geology, surficial geology, aeromagnetics and gravity. Prior to field work, a map at 1:250 000 would be prepared showing the varying element associations across the survey area. This is most readily done by plotting at each sample site those elements that occur in greater amount than the 90th or 95th percentile.

The difficulty in interpreting the results for this area has been reduced by information gained during brief follow-up studies carried out by Y.T. Maurice and the author on the Melville Peninsula portion of the Foxe Fold Belt (Cameron, 1979a; Maurice, 1979). In addition, W.C. Morgan, who was responsible for much of the geological mapping of the region, has made unpublished information and his rock collection available to the writer.

The pH of surface waters has an important effect on the migration of elements and their precipitation in lake sediments. This region has a wide range of pH. There are three broad zones of weakly alkaline pH (Fig. 8, 9), this being usually related to carbonate minerals in bedrock or overburden. Zone PHA (Fig. 9) is alkaline because of marble and dolomite near the base of the Piling Group. It is possible that the alkalinity in zone PHB along the coast derives from glacial drift containing detritus derives from the lower Paleozoic limestones and dolomites that outcrop to the west on islands in the Foxe Basin. For zone PHC there is no readily discernible feature apparent in the geological maps.

Zones PHD and PHE have acidic lake waters. The acidic nature of zone PHD is caused by oxidation of the sulphidic, graphitic schists of the lower Piling Group. The zone extends over the basal strata of upper Piling turbidites. These too must have appreciable sulphide, with little carbonate to neutralize the acid formed during weathering. The acidic nature of the surface waters decreases somewhat over the higher Piling strata exposed in the central part of the synclinorium. In the southern limb of the synclinorium the waters are acidic in zone PHE, underlain by rocks at the same stratigraphic level as those that underlie zone PHD. Thus the zones PHA, PHD and PHE well display the broad features of the synclinorium, with basal, carbonate-bearing strata, overlain by sulphidic strata and these by sediments with lesser amounts of sulphide, but also lacking carbonate.

The close disposition of marble and dolomite to sulphidic schists has doubtless caused precipitation barriers that may substantially influence the trace element contents of lake sediments. The acid formed during the weathering of sulphides greatly increases the solubility of some elements, including Fe, Mn, Zn, Cu, Ni and Co. If these acidic waters then enter a lake in marble and dolomite terrane with neutral to alkaline pH, these metals will largely precipitate. In this region, precipitation barriers are likely best developed near the conjuction of pH zones PHA and PHD.

Other variables, apart from pH, that should be considered during interpretation of lake sediment data are the loss on ignition (LOI), Fe and Mn contents of the samples. This information is given in the Open File release (Geological Survey of Canada, 1979). LOI is a measure of the organic content of the sample. Since organic material and Fe and Mn oxides are good adsorbents of dissolved trace metals, higher contents of one or more of these variables may be associated with increased contents of trace metals (Table 1). However, these materials are seldom the cause of multi-sample anomalies, such as those described below.

Interpretation of the element maps (Fig. 10-22) will start in the northern area of Archean outcrop. These maps indicate that the gneiss-migmatite terrane can be subdivided into three large blocks (Fig. 23), the primary identity of which have been obscured by metamorphism. Block A and, to a lesser extent, block C are more mafic in composition compared to block B, with higher contents of elements associated with mafic rocks, such as Ni, Co and Cu. The mutual boundaries of the blocks are sharp and are best shown by the 26 ppm Ni contour (Fig. 15). Further discrimination between the blocks is shown on the As map (Fig. 19); block A generally has values greater than the detection limit of 1 ppm As, while lake sediment samples from blocks B and C are generally less. The boundaries of the blocks have a northeasterly trend, roughly parallel to the foliation of the gneiss and to aeromagnetic and gravity trends.

Block A contains minor remnants of the Mary River Group. This and the association of mafic elements in lake sediments within its boundaries suggest that it may be a metamorphosed greenstone belt. Block B to the south is

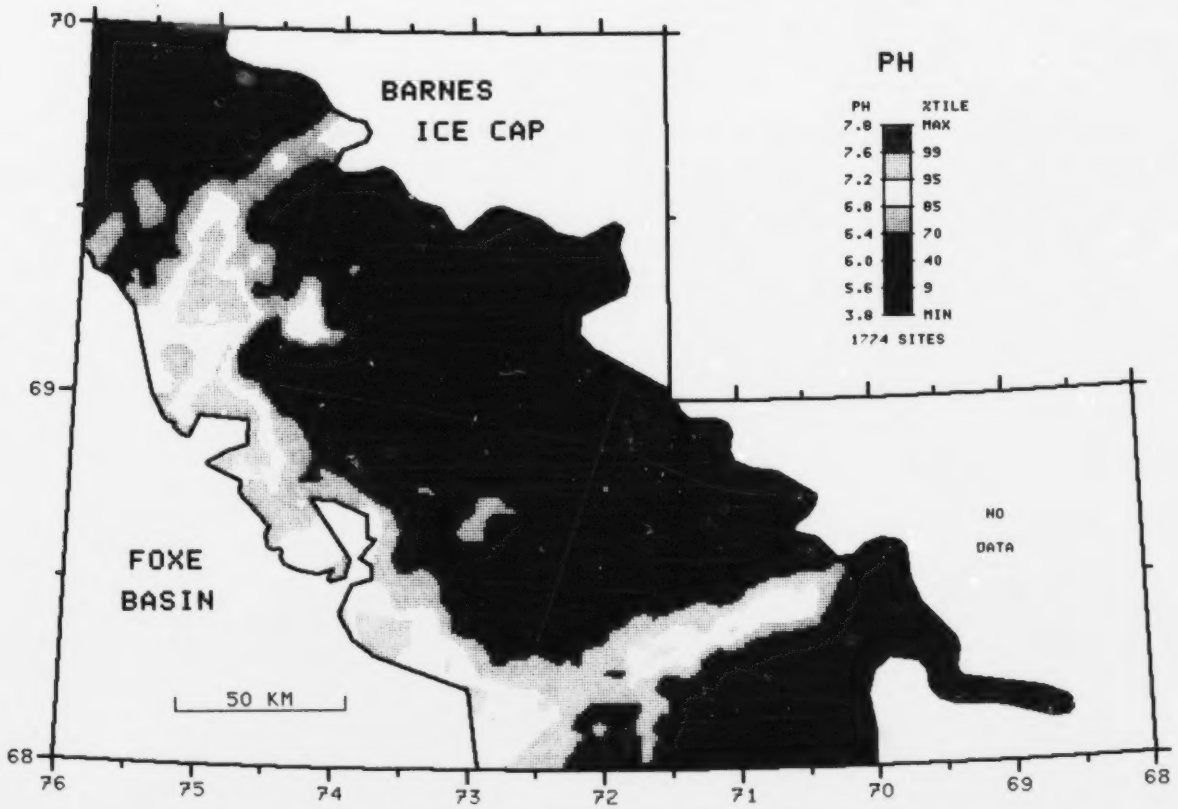

Figure 8. *Distribution of pH in lake waters.*

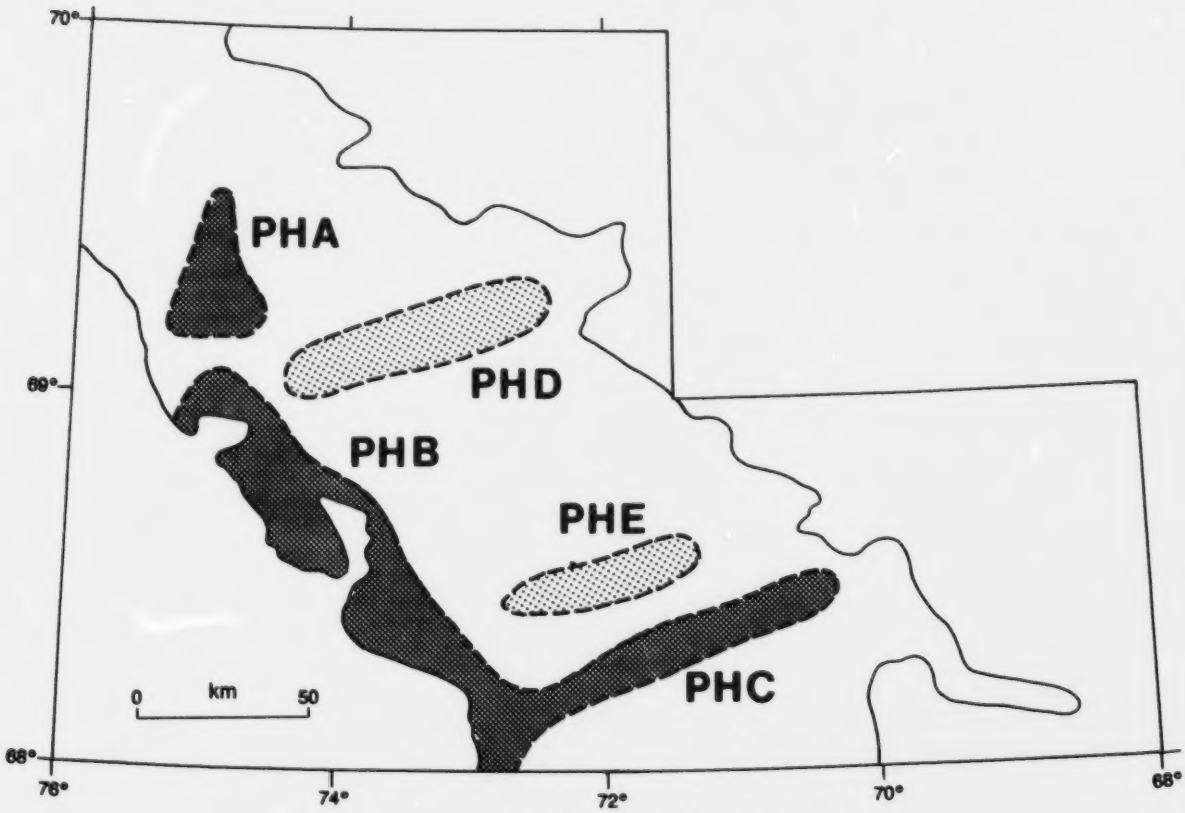

Figure 9. *Index map to pH zones.*

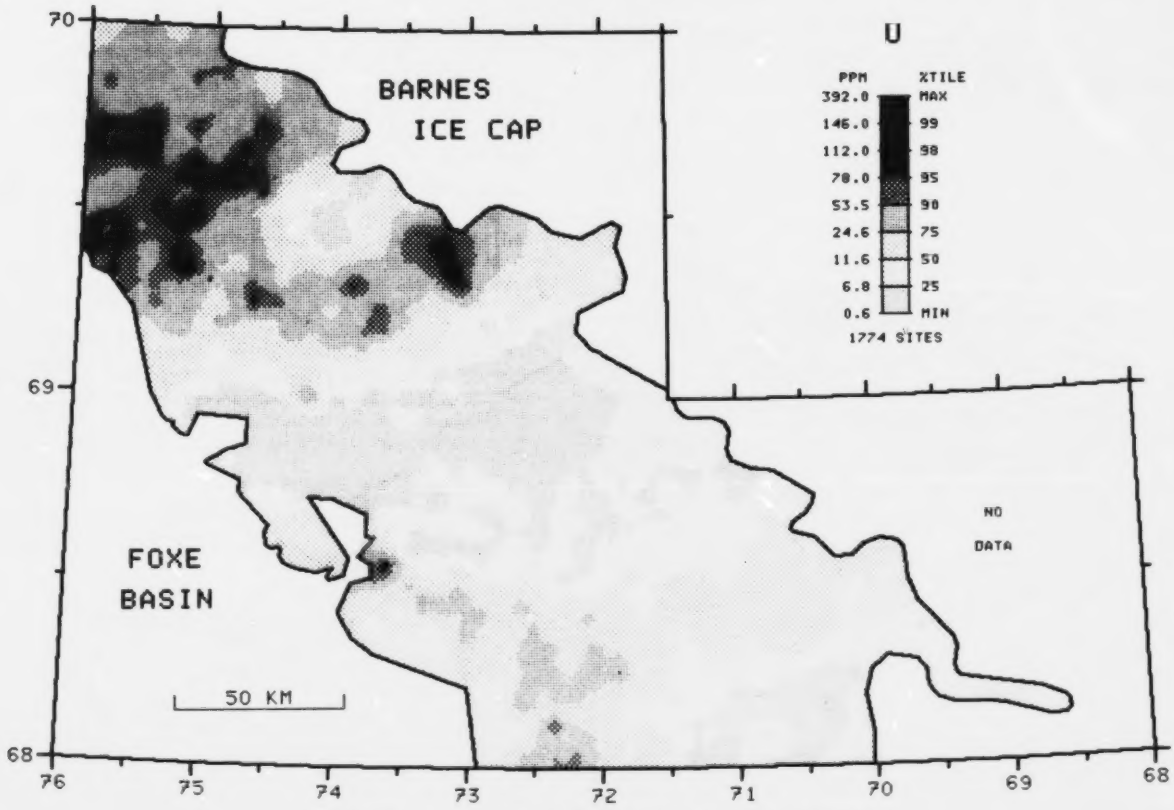

Figure 10. *Distribution of uranium in lake sediments.*

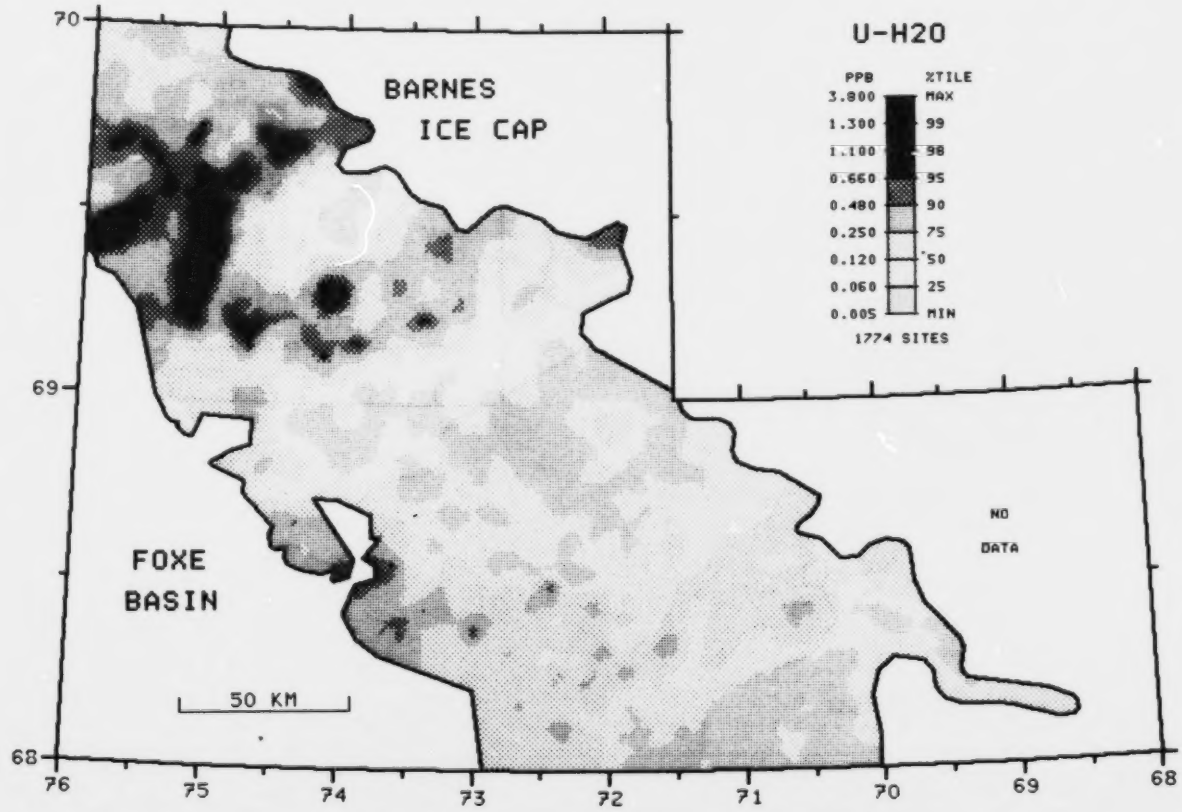

Figure 11. *Distribution of uranium in lake waters.*

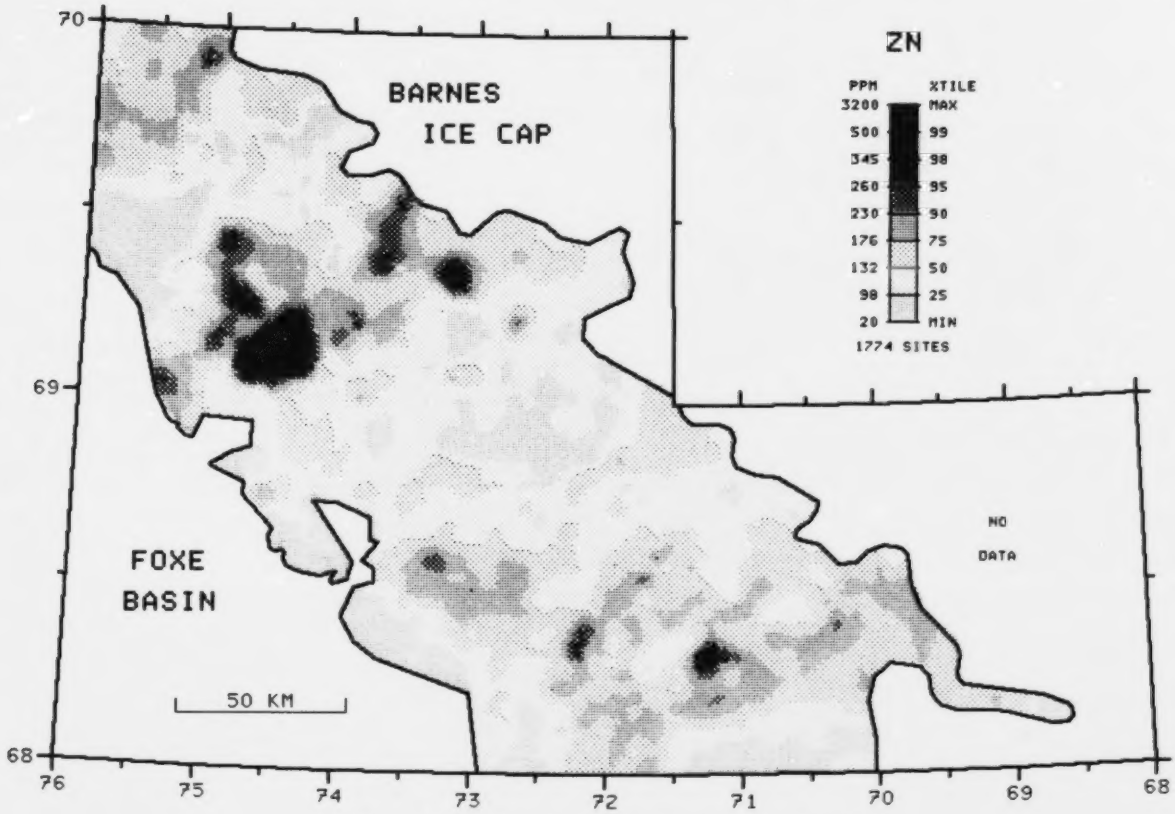

Figure 12. *Distribution of zinc in lake sediments.*

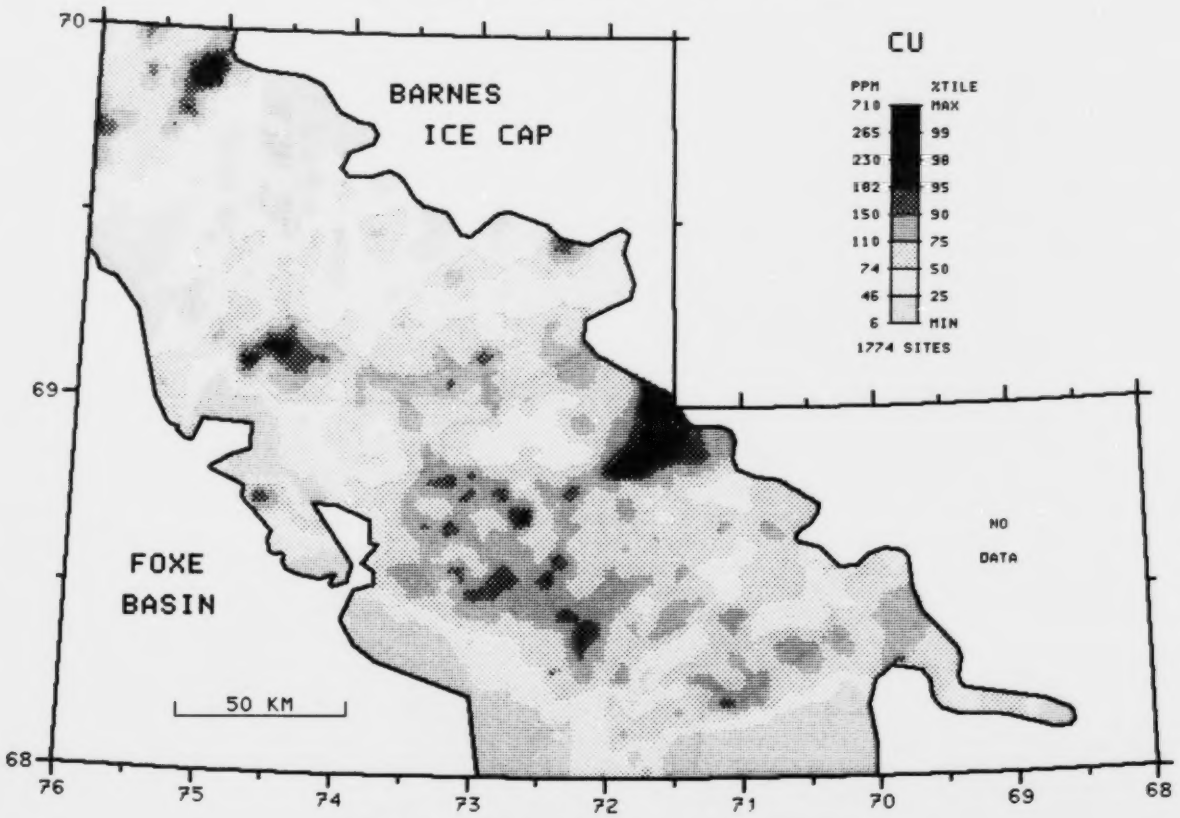

Figure 13. *Distribution of copper in lake sediments.*

more felsic in composition and was the preferred site for the generation and emplacement of granites during both the Kenoran and Hudsonian orogenies. It is coincident with a gravity low (Fig. 6). The extension of this block to the northeast under the Barnes Ice Cap is the site of one of the more notable gravity lows on Baffin Island, with contours to -100 mgal. Block C differs from A in that there are more Kenoran granitoids and complexly infolded Piling metasediments in C.

High U values are largely confined to the northern basement area, with two principal trends discernible in the data (Fig. 10, 23). There is an arcuate zone E associated with the Kenoran granitic intrusives and also, possibly, with the pegmatites near the basement-Piling contact. There is a second zone D orientated along block B associated with Hudsonian granites. For both zones D and E, high U values are also present in gneiss terrane between the granitoids. Note that the uraniferous granitoids of zone E form the northern boundary of the Foxe Fold Belt in this region.

An explanation should be given for the relationship of high U values in lake sediments to the bedrock composition. The levels of U found in sediment samples along zones D and E are high to very high by comparison with data from other regional geochemical reconnaissance areas of the Canadian Shield (Table 1). Such anomalous values may relate to point sources of U mineralization, or, more likely, extensive areas of bedrock with moderately high contents of labile U. Lake sediment values in the hundreds of ppm may derive from large surface areas, e.g., granite with only, say, 10 ppm, provided that the U is in a mineralogical form that can readily be dissolved by groundwater. High U is found in lake waters where the uraniferous zones intersect or overlap areas where the surface waters have a neutral to weakly alkaline pH, e.g., where zone E intersects marble and dolomite terrane. This reflects the marked increase in the partitioning ratio for U sediment/U water as the pH increases above 7 (Cameron, 1980).

Anomaly 1 (Fig. 24) is in Block A. It is characterized by high values for Pb to 395 ppm and there is a related Pb anomaly (1a) to the west. High values for Cu, Mo, Ag, As and Zn are associated with the Pb. The 1:250 000 geological mapping of the region does not indicate a change of bedrock type within the anomalous area, compared to that surrounding. All are mapped as gneiss (Morgan, 1983). However, the highest Pb values lie several kilometres along strike from a small outcrop of Mary River Group rocks. On the southwesterly extension of block A, outside the survey area, in Mary River Group rocks, a thin zone of disseminated galena with chalcopyrite and sphalerite was found during mapping (Morgan, 1982). This is in garnet amphibolite boudins in schist and gneiss. Anomaly 1 may reflect similar mineralization.

Note also anomaly 2 (Fig. 24), which covers an extensive area over Kenoran granite, with lake sediment values of >35 ppm Pb and >50 ppm U. This likely represents a U- and Pb-rich granite.

Some of the most interesting geochemical anomalies in the survey area are over lower Piling metasedimentary rocks along the northern margin of the fold belt. Anomaly 3 contains very high levels of Zn, Ni, Co, Cu, F and Mn, with, for example, Zn values to 3200 ppm. It occurs at the western limits of zone PHD (Fig. 9) of acidic lake waters developed over sulphidic, graphitic schists of the lower Piling Group. As discussed earlier, some of the high values for metals may be explained by precipitation barriers, where acidic, metal-rich waters flow over adjoining carbonate terrane. This is not the entire explanation for anomaly 3, however, since some of the highest metal values are in acidic lakes. A sample of sulphide facies iron-formation from the area contains 3400 ppm Zn, 610 ppm Cu, 510 ppm Ni, 270 ppm V, 85 ppm As, 85 ppm Mo, 41 ppm Co, 26 ppm Pb, 2.6 ppm Hg and 60 ppb Au. For all except Pb, these are unusually high values for a sedimentary rock and are similar to results from sulphidic, graphitic schists sampled on Melville Peninsula (Cameron, 1979a). Weathering of this material can readily

Table 1. Median element values for total Baffin regional geochemical reconnaissance (RGR) data grouped on the basis of Mn, Fe and LOI concentration; comparison with median values for all RGR lake sediment samples.

	Manganese <1000 ppm	Manganese >1000 ppm	Iron <10%	Iron >10%	Loss on ignition <20%	Loss on ignition ≥20%	All RGR
Number of samples	1721	53	1723	51	1653	121	40988
Element							
Zn ppm	130	184	130	154	132	124	86
Cu ppm	74	88	74	114	74	64	24
Pb ppm	14	21	14	19	14	13	3
Ni ppm	40	52	40	45	41	30	13
Co ppm	15	29	15	20	16	11	7
Ag ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mo ppm	2	3	2	6	2	3	2
As ppm	4	5	4	4	5	0.5	0.5
$U_{sediments}$ ppm	11.4	15.5	11.5	13.8	11.4	15.1	4.6
U_{waters} ppb	0.12	0.13	0.12	0.10	0.12	0.13	0.05
F_{water} ppb	10	10	10	10	10	10	34
Mn ppm	295	1300	300	225	310	200	240
Fe%	3.95	6.70	3.95	12.4	4.1	2.9	1.6
LOI%	7.4	8.2	7.2	13.0	7.0	24.8	29.8
pH	6.1	6.3	6.1	6.1	6.1	6.6	6.4

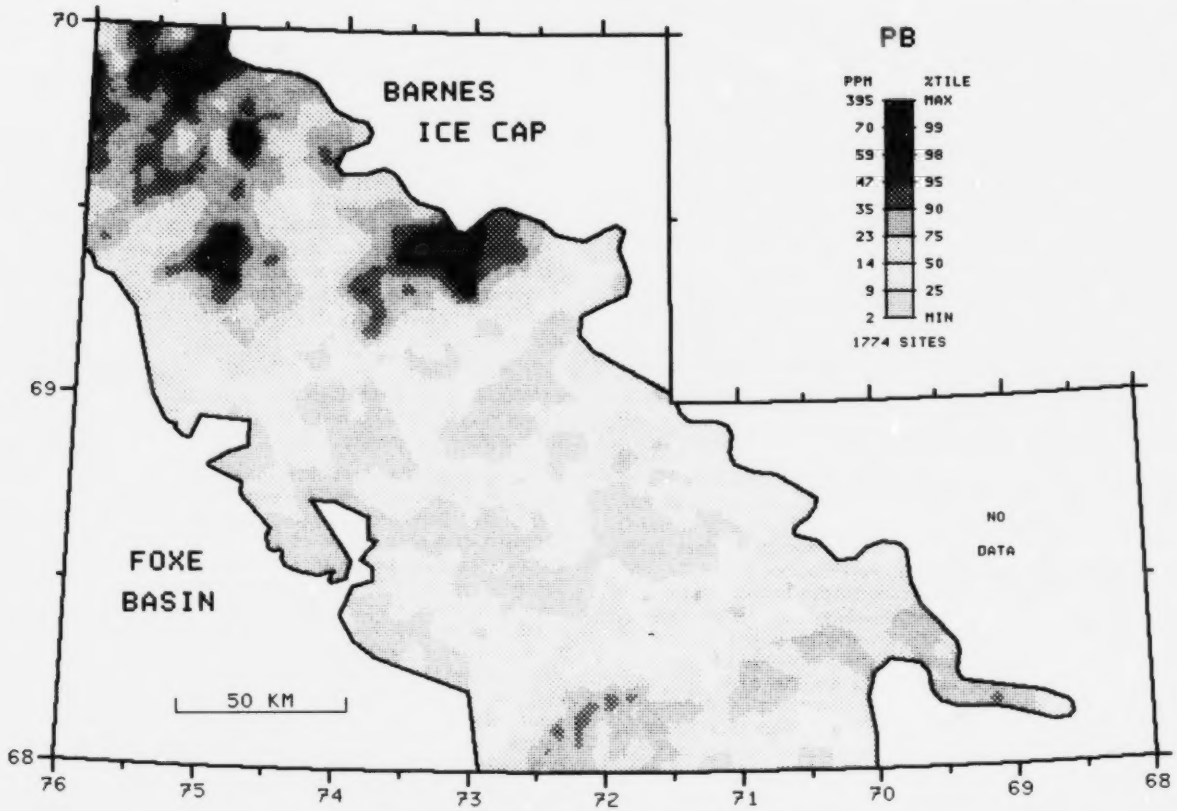

Figure 14. *Distribution of lead in lake sediments.*

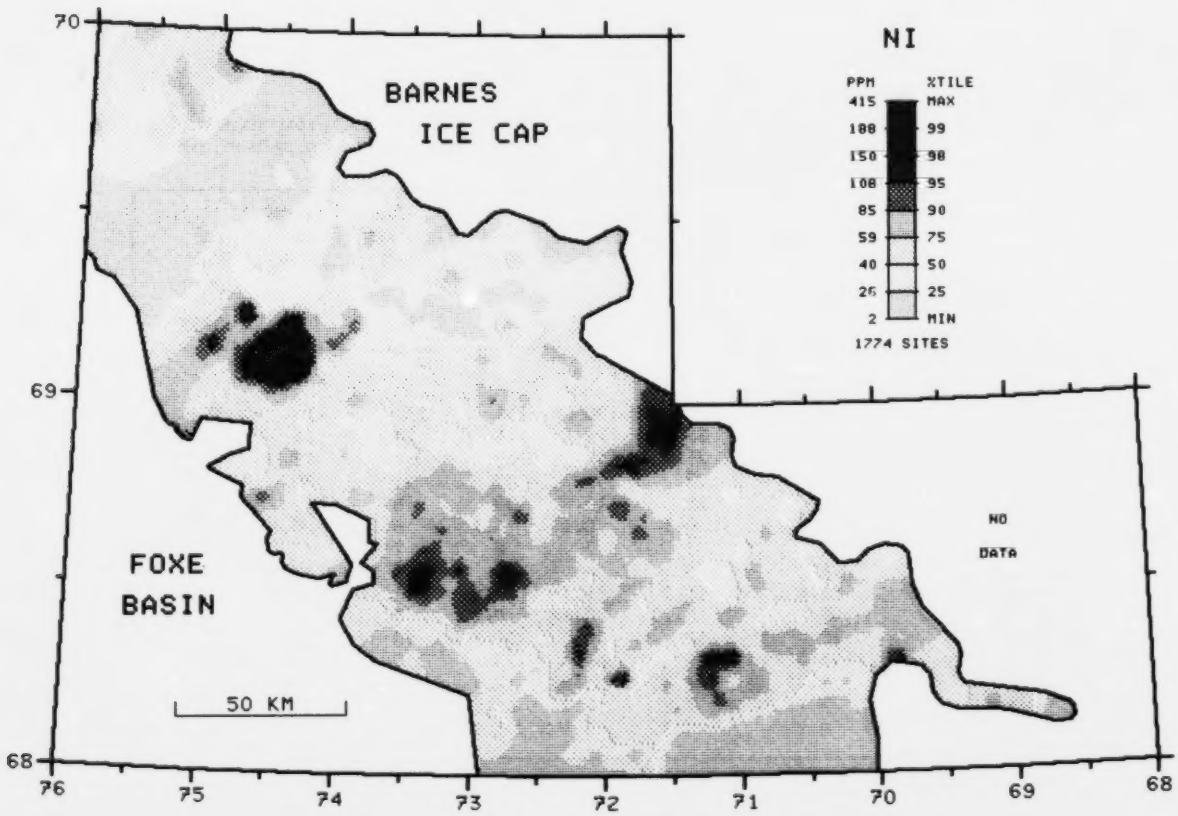

Figure 15. *Distribution of nickel in lake sediments.*

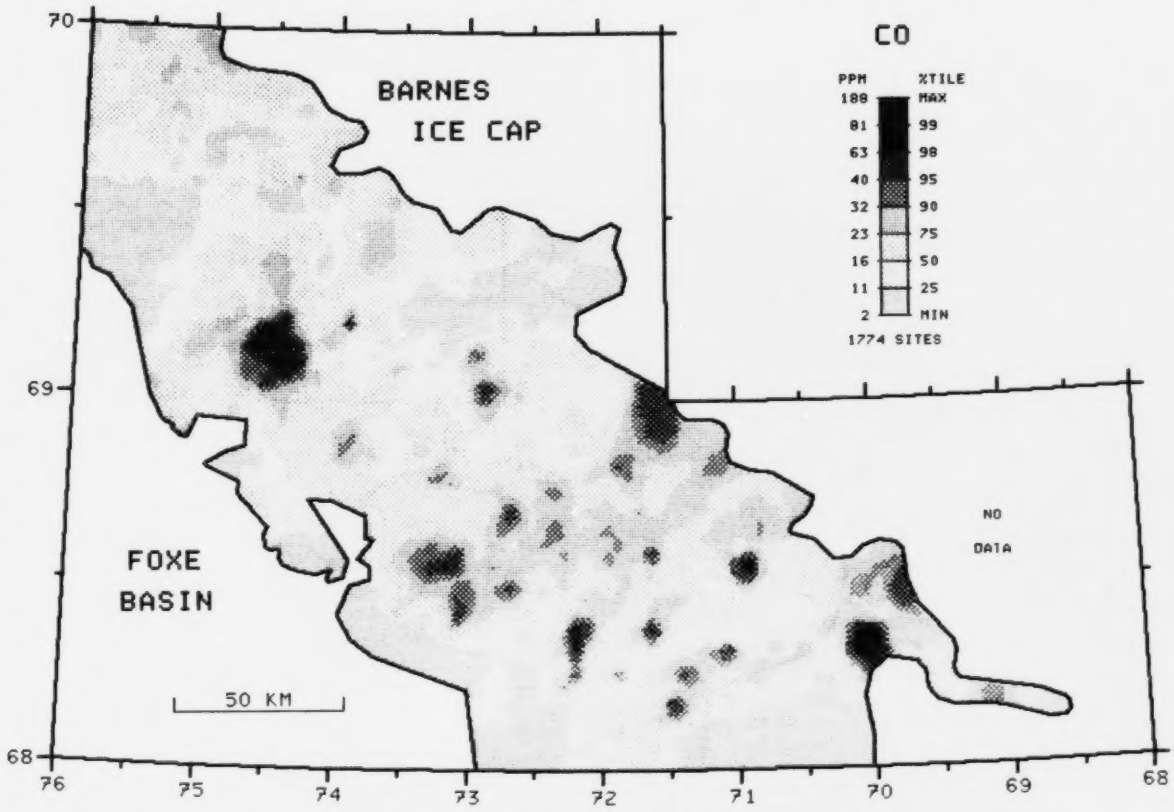

Figure 16. *Distribution of cobalt in lake sediments.*

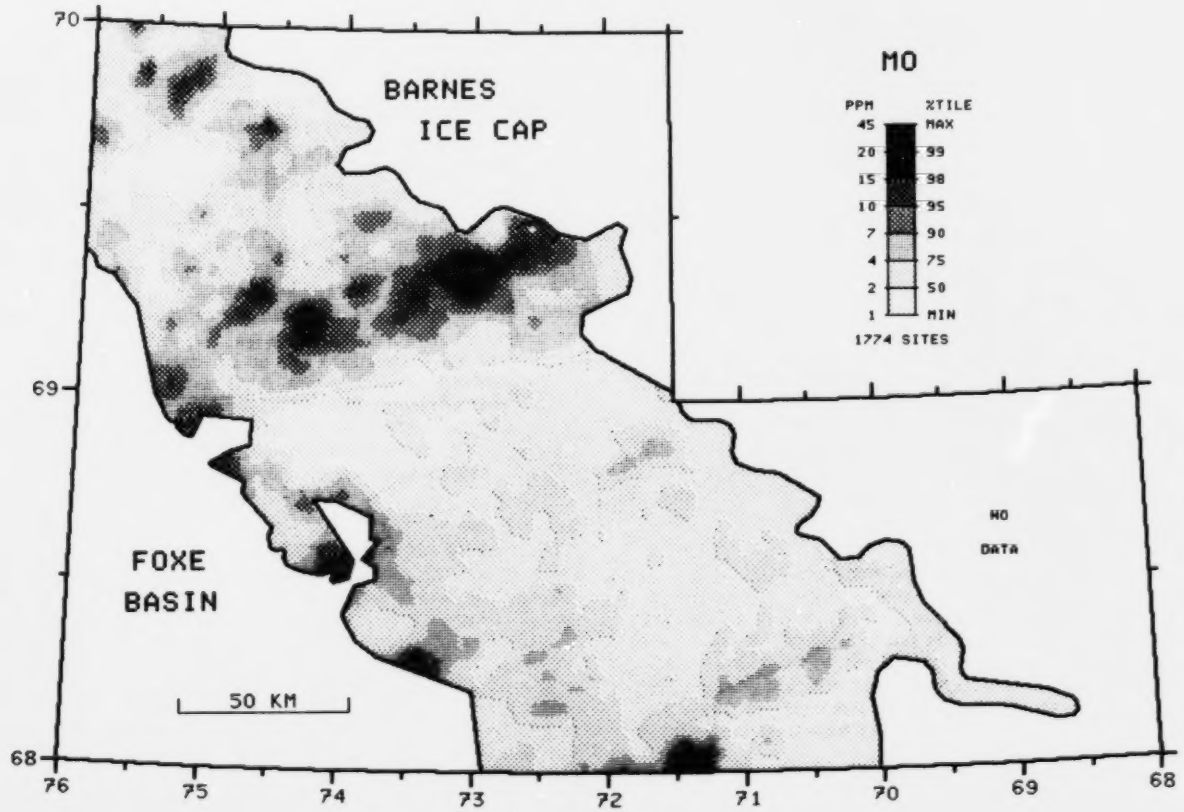

Figure 17. *Distribution of molybdenum in lake sediments.*

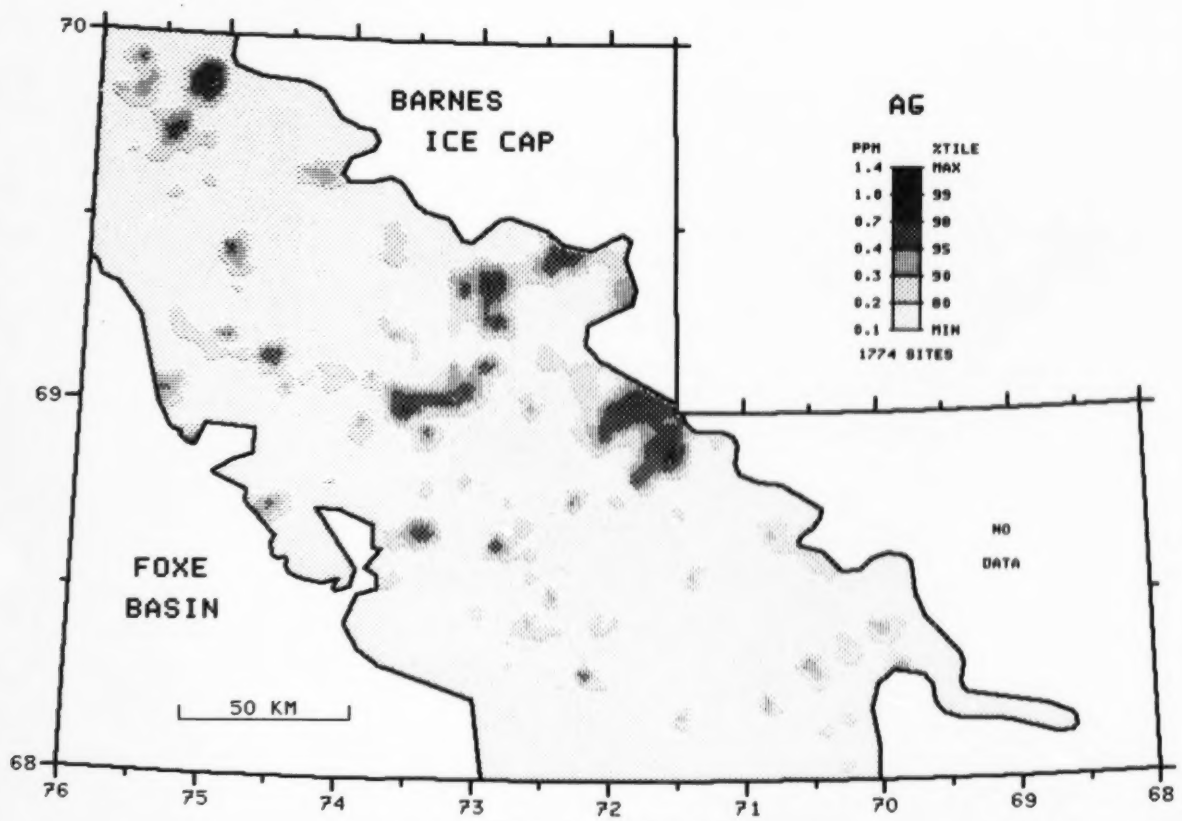

Figure 18. *Distribution of silver in lake sediments.*

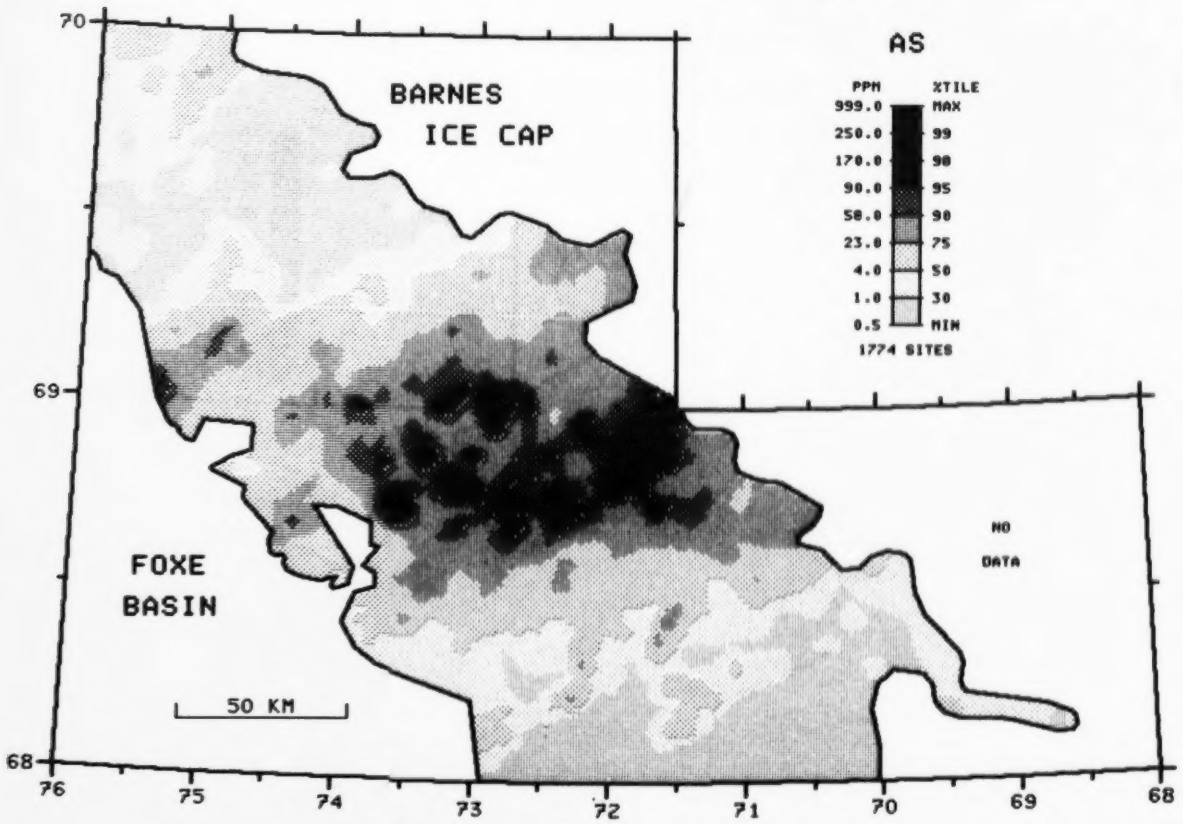

Figure 19. *Distribution of arsenic in lake sediments.*

produce the element values found in anomaly 3. The strongly acidic nature of the surface waters and the electrochemical effect of the graphite in the rocks being weathered greatly enhances the quantity of base metals that can dissolve and then be precipitated in lake sediments (Cameron, 1979b). While there may be some potential for base metal mineralization of the "shale-hosted" type associated with the sulphide-rich schist (see also Sangster, 1981), the intensity of this anomaly is, in part at least, related to favourable environmental conditions.

Anomaly 4 (Fig. 24) is coincident with the embayment of Piling strata into basement terrane. It is characterized by an abundance of marble and dolomite and, consequently, the surface waters have a neutral to weakly alkaline pH. Thus, in contrast to the previous anomaly, the environmental conditions are less favourable to the solution of base metals and the development of intense lake sediment anomalies. It is thus of interest that some relatively high values for Zn and Pb are found in this area and southwestward to the coast along the Piling outcrop. The most anomalous lake sediment sample contains 500 ppm Zn, 118 ppm Pb and 106 ppm Cu and is being deposited in a lake of pH 7.4. This should be considered as a prospective area for Pb-Zn mineralization in marble and dolomite, particularly in light of the occurrence of the Sorte Engel Pb-Zn deposit in marble and dolomite of the same age at Marmoralik on the coast of West Greenland. During geological mapping of the anomaly 4 area, traces of galena and Cu minerals were found in marble, dolomite and calc-silicate gneiss (Morgan et al., 1975).

The highest values for Mo occur over Kenoran granites flanking the fold belt to the north (anomaly 5, Fig. 24). Mo-rich granites are not uncommon, so that it might reasonably be concluded that the granites are the source of the anomaly. However, this most obvious interpretation may not be the correct one. The alternative explanation given here should be considered tentative in the absence of field studies; but, correct or not, it provides a useful illustration of the effect of the local surface environment on reinforcing or inhibiting the development of anomalies.

It was noted above that a sample of sulphide facies iron-formation contains 85 ppm Mo, a high value for a sedimentary rock. Samples of sulphidic, graphitic paragneiss from Melville Peninsula contain up to 850 ppm Mo (Cameron, 1979a). The iron-formation is to the south of the Mo anomaly in granites, being outlined by the aeromagnetic high (Fig. 7) and by the acidic zone PHB (Fig. 8, 9).

In acidic water Mo is insoluble as $HMoO_3^-$ (Hansuld, 1966). Thus Mo present in the sulphidic rocks will be retained in the soils and not transported to the lakes. By contrast, if Mo-rich material is carried by glacial action to areas of near-neutral to alkaline pH, the element will form the soluble anion MoO_4^{2-}, in which condition it can move to the lakes. This appears to be the explanation for anomaly 5 (Fig. 24). The granites form domes, partly surrounded by Piling metasedimentary rocks. Glacial action could readily have smeared Mo-rich detritus from the acidic paragneiss terrane over the granitic areas where the pH is in the range 6 to 7. The stability boundary between acid molybdate and molybdate anions is about pH 6.

Turning south, two of the most striking geochemical features of the fold belt are the distributions of As and U. The central part of the fold belt lacks U, but has an extremely high content of As. Indeed this is one of the most arsenical areas of Canada and, possibly, in the world. North of a dividing line F (Fig. 23), based on the 10 ppm As and U contours, most samples have >10 ppm As and <10 ppm U, while the converse is true south of the dividing line. Note too that the distribution of Pb in the fold belt is broadly similar to U. The geochemical boundary is broadly coincident with the outcrop of the amphibolite-ultramafic unit and the anatectic front (Fig. 4).

There are two possible interpretations for these U and As distributions: that they are related to stratigraphic change or to metamorphism. Because of the synformal nature of the fold belt, metamorphic grade parallels the stratigraphy, confusing interpretation. The central part of the fold belt, occupied by upper Piling turbidites, is the lowest grade region.

A stratigraphic interpretation for the U and As distributions is as follows. The rocks south of the geochemical boundary, although now migmatized, are Archean basement and lower Piling clastic sediments derived from the Archean craton. North of the fold belt, the Archean basement has been shown to be relatively enriched in U and depleted in As. North of the geochemical boundary F (Fig. 23), the turbidites were derived from an oceanic, volcanic source, not the craton, and excess As was contributed by submarine exhalations. This explanation is consistent with the synformal nature of the belt and with the presence of amphibolite and ultramafic rocks near the boundary between lower Piling miogeoclinal sediments and the turbidites of the upper Piling.

The alternative explanation is that the element patterns represent differing element mobilities during metamorphism. Uranium moved into high grade, migmatized zones, while As, which is relatively volatile in some forms, moved into the central, lower grade portion of the fold belt. On the basis of the lake sediment geochemical data alone, it is not possible to distinguish between these alternatives.

Two base metal anomalies have been outlined in the southern part of the fold belt (Fig. 24). Anomaly 6 contains high values for Ni, Co, Cu and Zn. It is within or near to the amphibolite-ultramafic unit and is, therefore, at approximately the same stratigraphic level as anomaly 3 in the northern sector of the fold belt. Thus, as well as sharing a similar element assemblage as anomaly 3, its genesis may be similar, that is stratiform mineralization from a submarine exhalative source. Anomaly 7 has elevated metal contents for Cu, Ni, Co, Ag, As, Zn and Mo. Geological mapping at 1:250 000 scale shows no unusual rock type in this area; simply upper Piling turbidites.

DISCUSSION

Interpretation of the geochemical data from Baffin Island has focused, firstly, on their use for outlining mineralization and, secondly, on their relationship to major geological features.

Geochemical maps have but rarely been employed to understand the geological history of a region. The work of Johnstone et al. (1979) in the Scottish Highlands is a notable example to the contrary. It is clear that, when considered together, geochemical and geophysical maps can significantly elaborate our understanding of the geological history of portions of the crust, particularly complex, metamorphosed terranes where the original nature of the rocks has been obscured. Surficial geochemical data are useful for this purpose on two scales. First, the broad, regional patterns that help subdivide gneiss – migmatite terrane. Secondly, to subdivide rock units, such as Pb-rich and Pb-poor parts of plutons. These geochemical data will be most useful when they are available prior to geological mapping.

The primary purpose of regional geochemical reconnaissance surveys was to assist in the discovery of mineral deposits and to help evaluate the mineral potential of broad regions. While it is not appropriate to elaborate on the mineral potential of the region in the absence of follow-up field studies, the principal geochemical features of the Foxe Fold Belt on western Baffin Island, as these relate to metallogenesis, should be noted.

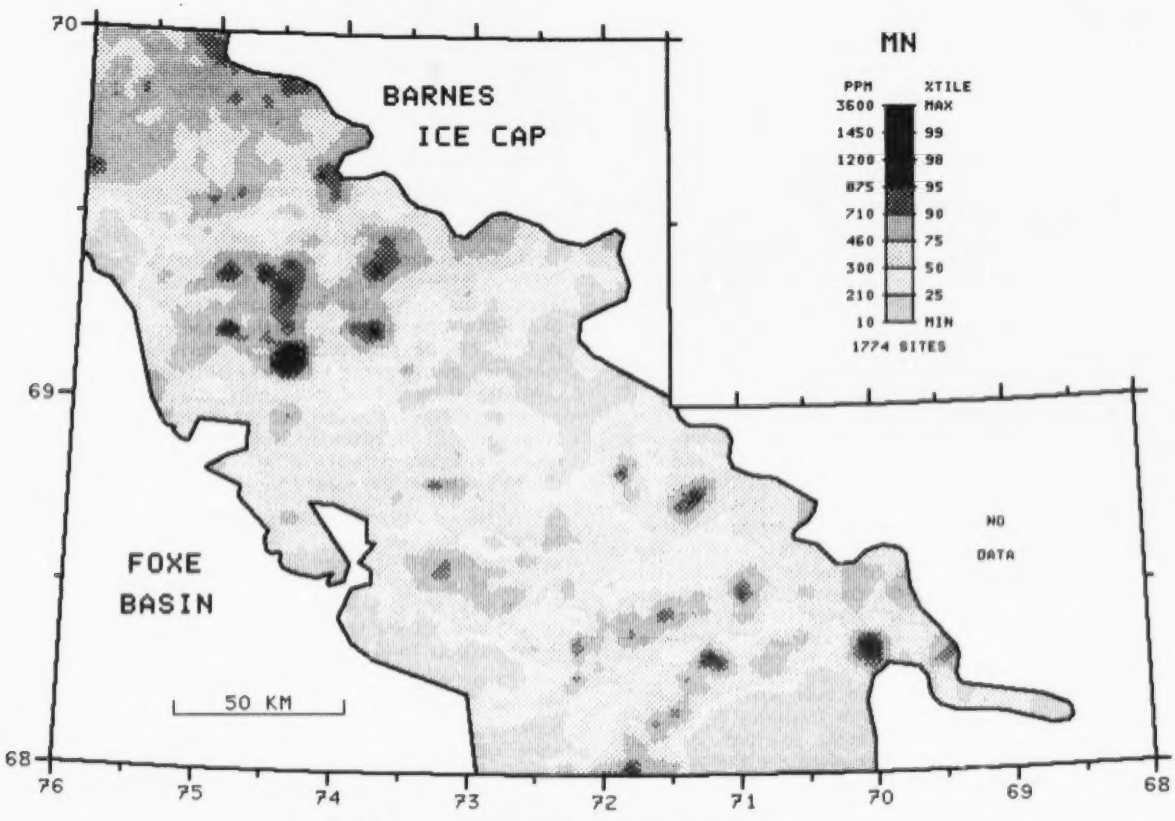

Figure 20. *Distribution of manganese in lake sediments.*

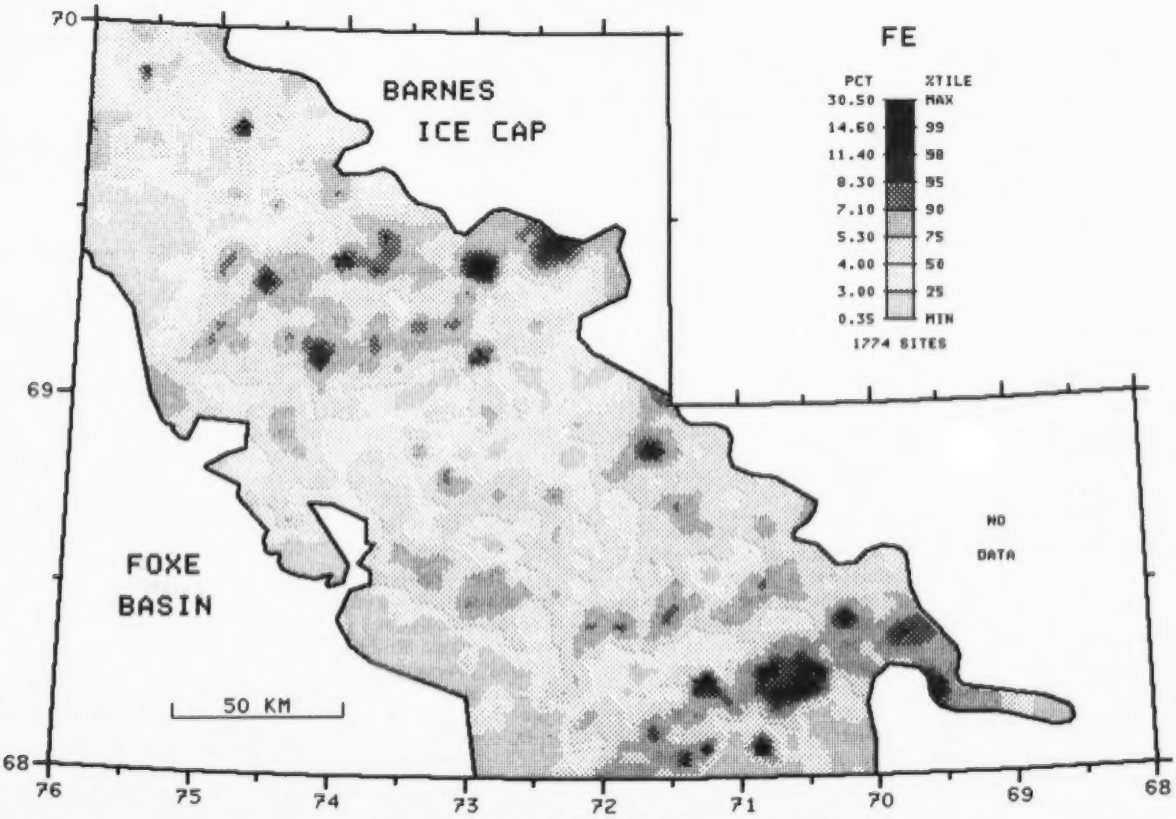

Figure 21. *Distribution of iron in lake sediments.*

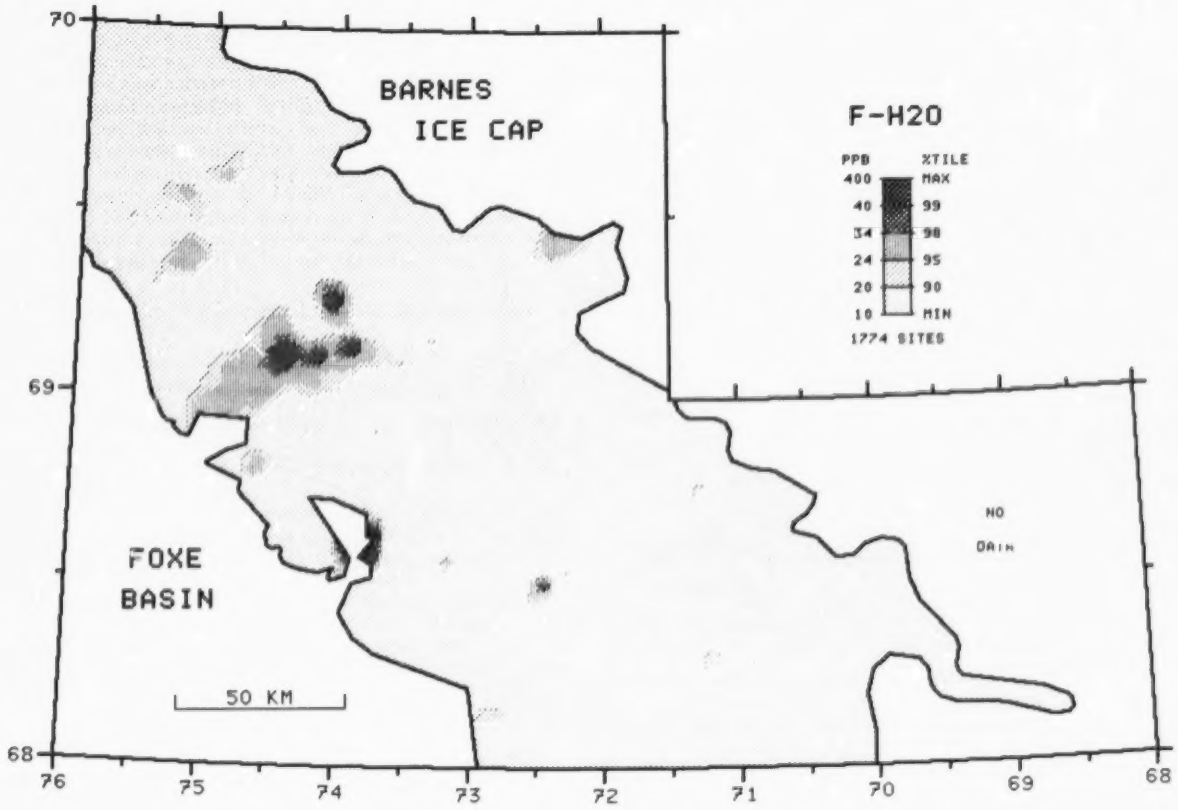

Figure 22. *Distribution of fluorine in lake waters.*

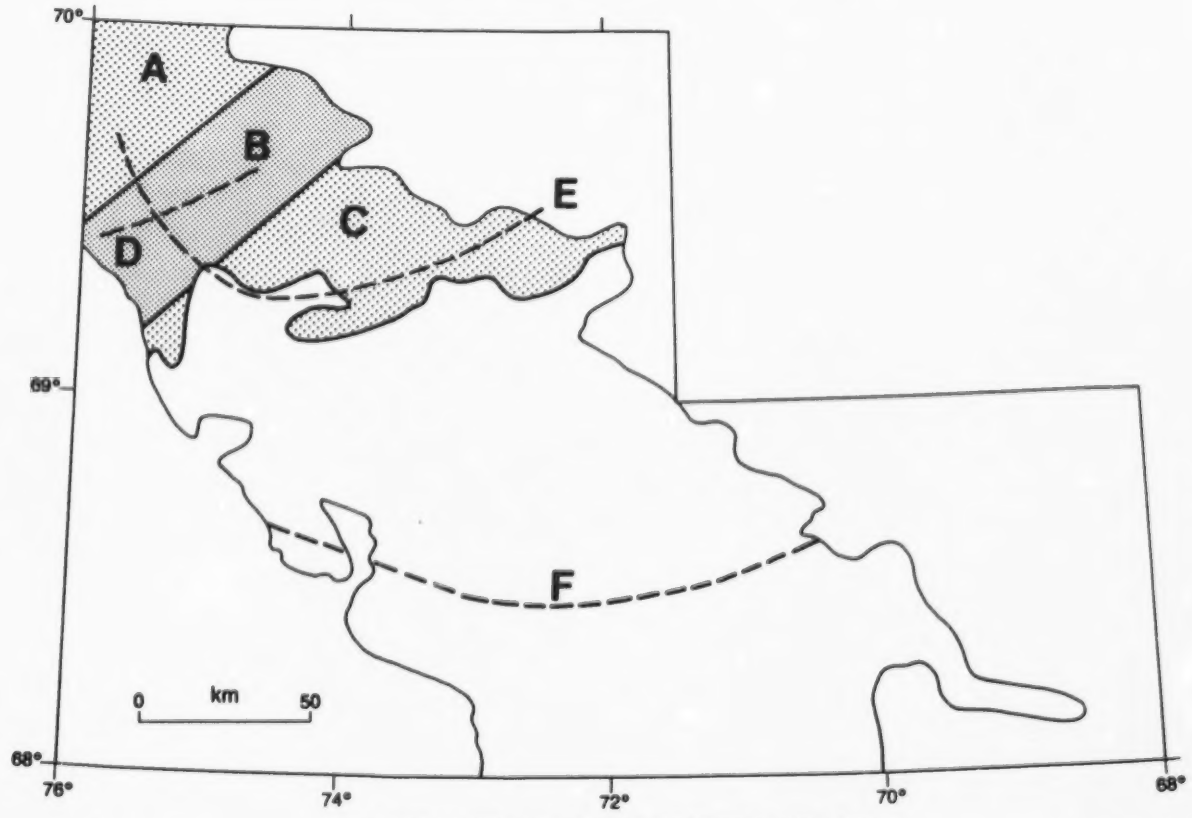

Figure 23. *Index map to geological/geochemical zones.*

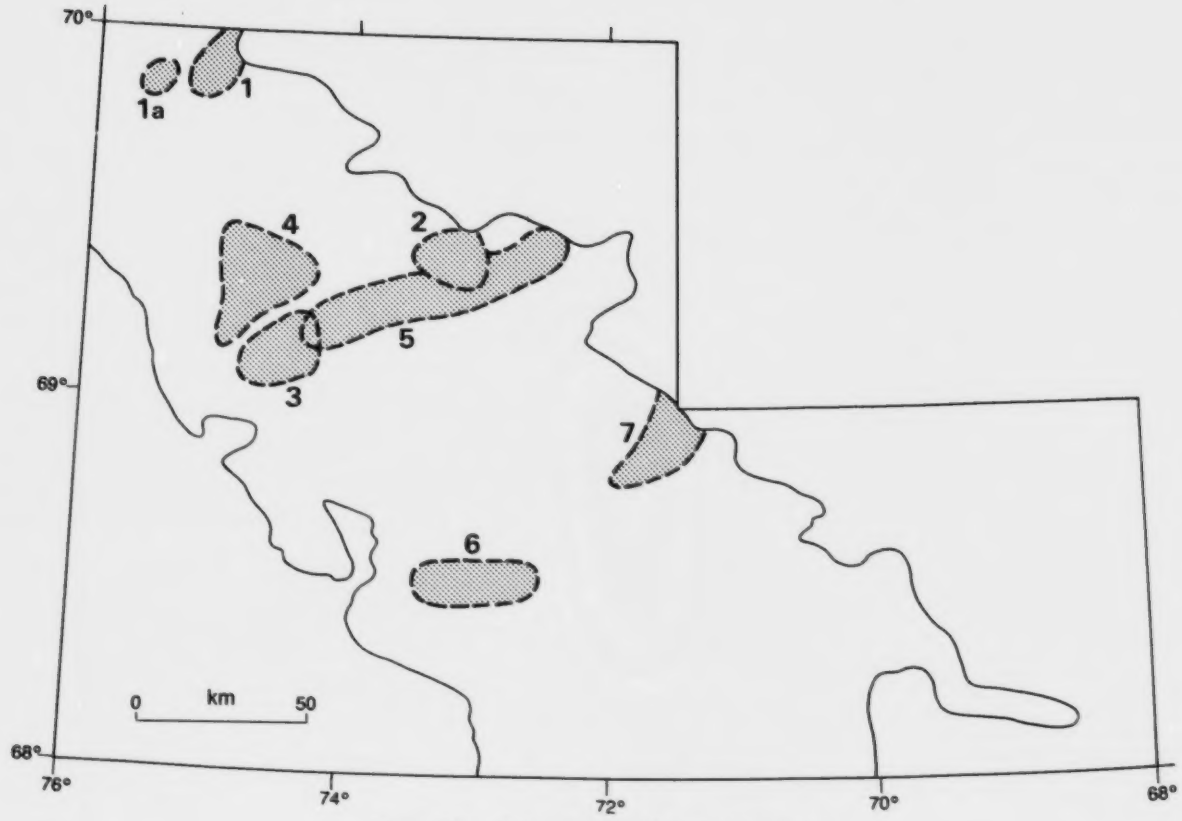

Figure 24. Index map to referenced anomalies.

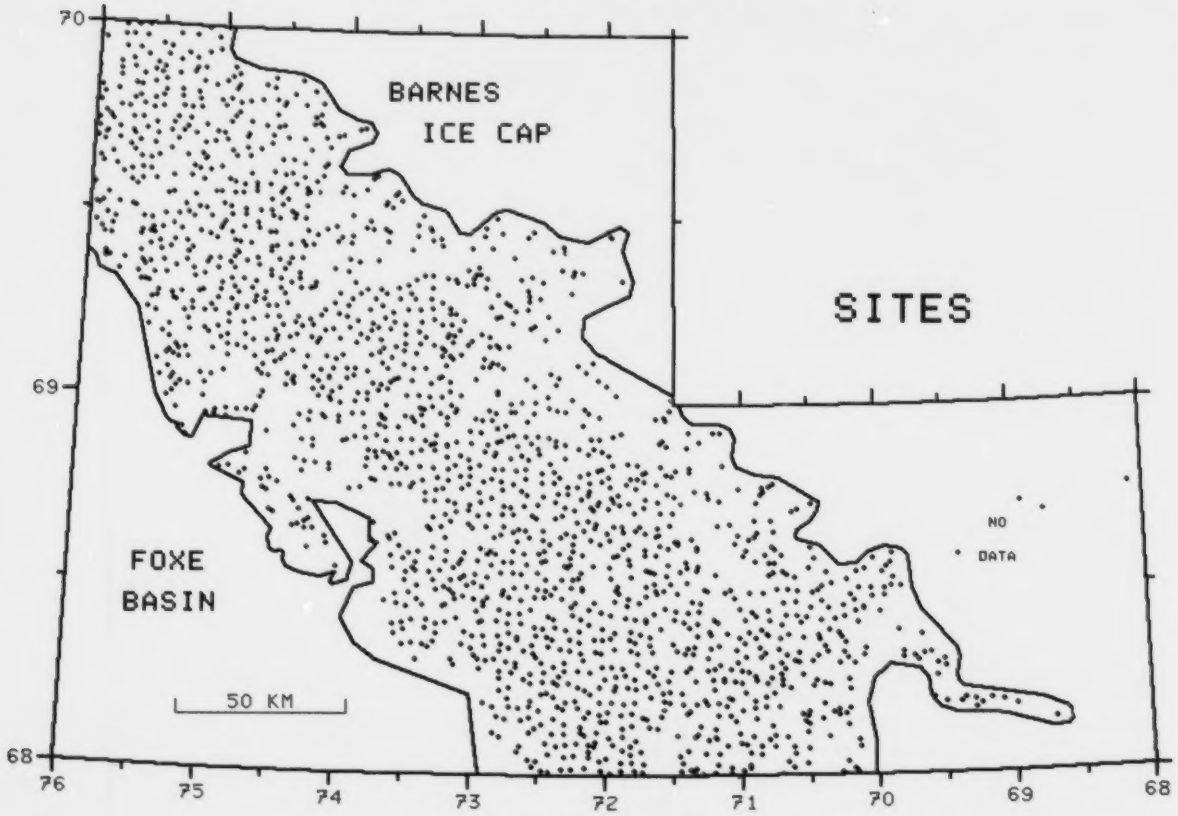

Figure 25. Sample location map.

The geological and geochemical data suggest a three part subdivision of the Aphebian rocks of the belt.

(1) At the base, miogeoclinal sedimentation, with a thick sequence of carbonates along the northern margin.

(2) A hiatus caused by rifting within the fold belt and the extrusion of volcanic rocks, now chiefly amphibolites. Extrusion was probably submarine and was accompanied by metalliferous exhalations. These spread across the basin depositing large quantities of metals in organic-rich muds. The waters of the basin may have been anoxic. In part, the exhalations and rifting may have been contemporaneous with carbonate sedimentation along the northern flanks of the fold belt.

(3) Sedimentation of a thick turbidite sequence prior to orogeny.

Most probably, mineralization was principally associated with stage (2) and may include (a) to (d) below:

(a) Ni-Cu mineralization in and near the ultramafic rocks.

(b) Base metal massive sulphide mineralization in or near the amphibolites.

(c) "Shale-hosted" base metal mineralization in the graphitic paragneiss and sulphide iron-formation. The high As values present in this sequence also indicate the possibility of Au mineralization being present.

(d) Pb-Zn mineralization in the marble and dolomite.

(e) Mineralization formed during metamorphism. The abundant pegmatites in pelitic zones near the northern margin of the fold belt indicate that metamorphism took place before water had been removed from these sediments.

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APPENDIX A
Sampling methods

Regional Geochemical Reconnaissance (RGR) lake and stream sediment and water samples were collected according to instructions, specifications and conditions provided by the Federal Government (Geological Survey of Canada) and/or the Provinces in contracts with experienced survey firms. The majority of all RGR areas were sampled at an average sample density of one sample site per 13 km^2. Remaining surveys, two in British Columbia, one in Saskatchewan and all of insular Newfoundland were carried out at approximately twice RGR sample density for increased resolution of the expected complex geochemical data base information.

In the early seventies, the basic RGR sample design incorporated a field and blind duplicate and a control reference sample in every analytical block of twenty samples to monitor and control sampling and analytical variance. In 1977, the basic sampling design for lakes was modified to include a cell duplicate sample collected from a site in a previously routinely sampled cell in a given analytical block. The cell duplicate site, together with the others, was incorporated into an unbalanced nested sampling design to monitor variability between lakes in a cell as well as to continue to provide systematic sampling and analytical control.

High wet strength paper bags, approximately 10 cm x 15 cm x 5 cm with a double fold top and water resistant glue were used to contain collected sediment samples and to facilitate sample drying. Water sample were collected in rectangular wide mouth linear polyethylene bottles.

Only lake types specified were sampled by helicopter-mounted crews utilizing a GSC developed sampling apparatus with an external winch and rope system. Sites were located in the centre-lake profundal basin position: shoreline sites were not accepted. An ideal lake would be 1 to 5 km^2 in size, at least 3 m in depth and constitute an active part of the drainage system in a 13 km^2 grid cell. Lakes too small to be shown on a 1:250 000 scale NTS map were not sampled. With the top several centimetres of sediment from the sediment-water interface washed out of the core barrel during retrieval of the sampler, the remaining material collected is an organic-rich sediment, commonly a green-brown to grey thixotropic gel. Samples with a dominant sand-gravel component or totally organic peat from swampland were not acceptable. Commencing in 1976, lake water samples were routinely collected at all lake sediments sites. Samples were taken at least 20 cm below the surface in water as free of suspended material as possible. Normally the crew member in the front of the cabin with the pilot was the navigator, notetaker, water-sampler while the crew member sitting aft operated the winch from an outside float-mounted platform to collect the lake sediment sample. An average traversing rate of 15 sample sites per hour was achieved while sampling on traverse. The overall survey sampling rate depended on the ferry time to and from traverses and the logistics of positioning gas caches.

APPENDIX B
Analytical methods

Determination of Zn, Cu, Pb, Ni, Co, Ag, Mn, Fe in lake sediments

A 1 g sample is digested in 6 ml of 1M HCL – 4M HNO_3 at 90°C for 2 hours. After cooling, the solution is diluted to 20 mL with deionized water, mixed and allowed to settle. The elements are determined by atomic absorption analysis using an air-acetylene flame with background correction for Pb, Ni, Co and Ag.

Determination of Mo and V in lake sediments

A 0.5 g sample is digested in 1.5 mL HNO_3 at 90°C for 30 minutes. O.5 mL 12M HCl is added and the extraction continued for 90 minutes at 90°C. After cooling, 8 mL of 1250 µm mL^{-1} Al solution is added, diluted to 10 mL with deionized water, mixed and allowed to settle. Mo and V are determined by atomic absorption using a nitrous oxide-acetylene flame.

Determination of U in lake sediments

A 1 g sample is weighed into a polyethylene vial, capped and sealed. The irradiation is provided by a Slowpoke reactor with flux density of 10^{12} neutrons cm^{-2} s^{-1}. The sample is pneumatically transferred from an automatic loader to the reactor where it is irradiated for 60 s. After 10 s delay, the sample is counted for 60 s with 6 BF_3 detector tubes embedded in parrafin. Calibration is carried out twice daily using natural materials of known U concentration as standards.

Determination of As in lake sediments

A 0.25 g sample is leached with 10 mL of aqua regia at room temperature for 2 hours and then heated to 90°C for a further 2 hours. After cooling, a 1.0 mL aliquot is taken and diluted to 10.0 mL with 0.5 M HCl in a test tube. Arsine is generated by the addition of 2% (w/V) sodium borohydride and the gas swept into a silica tube heated to 850°C in the light path of an atomic absorption spectrophotometer. Measurement is made at 193.7 nm against known standards. NB: The values obtained by this method are sometimes higher than the previously used (in earlier surveys) colorimetric method, depending upon sample type.

Determination of LOI in lake sediments

A 0.5 g sample is weighed into a beaker, placed in a cold muffle furnace and the temperature raised to 500°C over a 2-3 hour period. The sample is maintained at 500°C for 4 hours, cooled and reweighed.

Determination of U in lake waters

After collection, the water sample (~225 mL) is acidified with 3 mL 12 M HNO_3. Two weeks later, a 5 µmL aliquot is removed and spotted on a polycarbonate tape. The tape is irradiated for 1 hour with a flux density of 10^{13} neutrons cm^{-2} s^{-1}. The tape is then etched with 25% NaOH solution and the fission tracks counted with an optical counter fitted to a microscope. Calibration standards are subjected to the same procedure.

Determination of F in lake waters

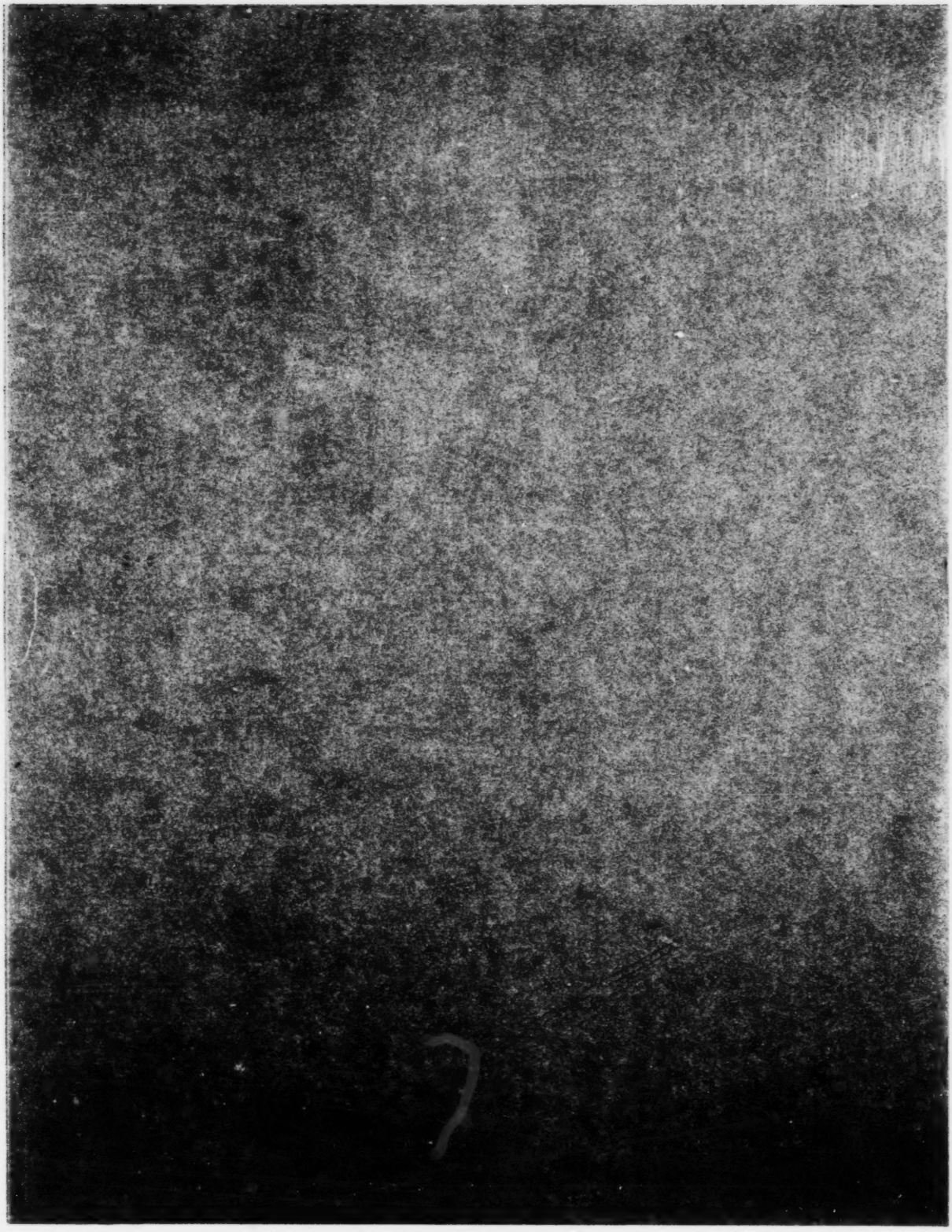
An aliquot of the water sample is taken and an equal volume of TISAB (total ionic strength adjustment buffer) is added. The mV reading is measured with an ion-selective electrode combined with a reference electrode and the F concentration found from a calibration graph constructed with known standards.

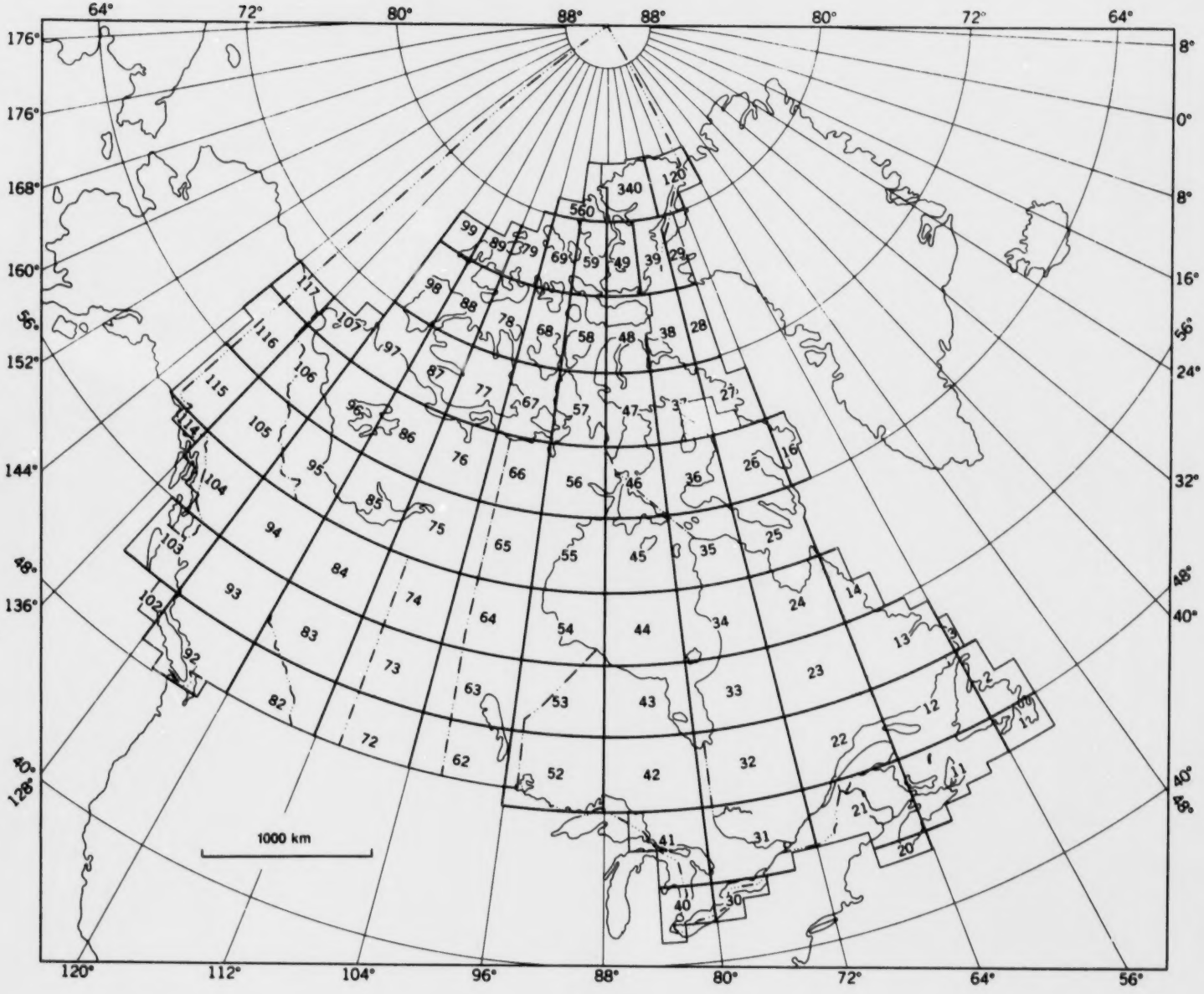
Determination of pH

The hydrogen ion activity is measured with a combination pH electrode and a specific ion meter which has been calibrated with standard solutions at pH 4.00 and 7.00.

Element	Detection limit	Assigned value (if below detection limit)
Sediment		
Zn	2	1
Cu	2	1
Pb	2	1
Ni	2	1
Co	2	1
Mn	5	2
As	1	0.5
Mo	2	1
Fe%	0.02	0.02
LOI%	1.0	0.5
U	0.2	0.1
V	10	5
Water		
U ppb	0.01	0.005
F ppb	20	10

Unless otherwise noted, the units of measurement are ppm.





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